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FARM WATER MANAGEMENT OPTIONS FOR DRAINAGE REDUCTION

Prepared for the
San Joaquin Valley Drainage Program
by the
Agricultural Water Management Subcommitte

OCTOBER 1987

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TABLE OF CONTENTS

Page

SECTION 1 EXECUTIVE SUMMARY 1-1

SECTION 2 STATEMENT OF THE PROBLEM 2-1

2.1 Geology 2-1

2.2 Irrigation and Salinization 2-2

2.3 Toxic Elements 2-3

2.4 Regulatory Pressure and Termination of Drainage Services 2-4

2.5 The Search for Solutions 2-5

2.6 Drainage Volume Reduction 2-5

SECTION 3 DRAINAGE RELATIONSHIPS 3-1

3.1 Introduction 3-1

3.2 Background 3-2

3.2.1 Drainage Basics 3-2
3.2.2 Soils and Hydrogeology 3-6
3.2.3 Sources of Excess Drainage 3-7
3.2.4 Data Base 3-10

3.3 Drain Load-Flow Relationships 3-12

3.3.1 Basic Drain Load-Flow Relationships 3-12
3.3.2 Preliminary Analysis of Data Base 3-22

3.4 Management of Shallow Groundwater 3-25

3.4.1 Alternate Crops 3-25
3.4.2 Recycling Drain Water 3-33

3.5 Conclusions and Recommendations 3-36

3.5.1 Research 3-36
3.5.2 Monitoring 3-37

SECTION 4 IRRIGATION PRACTICES AND EMERGING TECHNOLOGIES 4-1

4.1 Introduction 4-1

4.2 Irrigation Performance Measures 4-1

4.3 Irrigation System Performance and Economics 4-4

4.3.1 Seepage Losses 4-9

4.4 Irrigation System Technologies 4-10

4.4.1 Surface Irrigation - Existing Technologies 4-10
4.4.2 Surface Irrigation - Emerging Technologies 4-12
4.4.3 Sprinkle Irrigation - Existing Technologies 4-16
4.4.4 Sprinkle Irrigation - Emerging Technologies 4-19
4.4.5 Trickle Irrigation - Existing Technologies 4-19
4.4.6 Trickle Irrigation - Emerging Technologies 4-21
4.4.7 Summary of Potential Uniformities and Efficiencies 4-21

4.5 Irrigation Management Technologies 4-21

4.5.1 Irrigation Scheduling 4-21
4.5.2 Drain Water Use 4-23
4.5.3 Leaching/Drainage 4-26

4.6 Areas of Education and Research 4-28

4.6.1 Demonstration Projects 4-28

4.7 Conclusion and Recommendations 4-29

SECTION 5 INSTITUTIONAL CHANGES AND ECONOMIC INCENTIVES 5-1

5.1 Introduction 5-1

5.2 Existing Programs 5-2

5.2.1 United States Bureau of Reclamation 5-2
5.2.2 U.S. Department of Agriculture, Soil Conservation Service (SCS) 5-3
5.2.3 U.S. Department of Agriculture, Agricultural Research Service, Water Management and Salinity Labs 5-3
5.2.4 California Department of Water Resources (DWR) 5-4
5.2.5 University of California Cooperative Extension (UCCE) and Farm Advisors 5-4
5.2.6 University of California Committee of Consultants 5-5
5.2.7 San Joaquin Valley Drainage Program (SJVDP) 5-5
5.2.8 Westlands Water District (WWD) 5-5

5.2.9 Broadview Water District (BWD) 5-6
5.2.10 Berenda Mesa Water District (BMWD) 5-6
5.2.11 Private Consultants 5-6
5.2.12 Summary 5-6

5.3 Water Management Incentives 5-7

5.3.1 Water Year 5-7
5.3.2 On-Demand Delivery 5-8
5.3.3 Pricing 5-9
5.3.4 Water Markets 5-10
5.3.5 Water Credits/Contract Changes 5-11
5.3.6 Capital Financing Options (Basin, District, and On-Farm Levels) 5-11
5.3.7 On-Farm Management Incentives 5-11
5.3.8 Fund Collection Options 5-12
5.3.9 Cost Sharing Options 5-12
5.3.10 Regulatory Pressure as an Incentive 5-13
5.3.11 Regional Drainage Authority 5-13
5.3.12 Land Use Changes 5-14
5.3.13 Participation in Agricultural Stabilization and Conservation Service (ASCS) Agricultural Conservation Program 5-15

5.4 Conclusions 5-15

5.5 Recommendations 5-16

SECTION 6 AN EDUCATION PROGRAM FOR DRAINAGE REDUCTION 6-1

6.1 Introduction 6-1

6.1.1 Importance of Drainage Reduction 6-1
6.1.2 It Is Everyone's Problem 6-1

6.2 Where to Begin: Demographics 6-2

6.3 Education Program Components 6-3

6.3.1 Expanded Use of the Mobile Lab 6-3
6.3.2 On-Farm Demonstrations 6-4
6.3.3 Workshops/Short Courses 6-4
6.3.4 On-Farm Water Conservation and Management Programs 6-5
6.3.5 Education Video Tapes 6-6
6.3.6 Drainage Action Team 6-6
6.3.7 Regional Newsletter/Periodic Information Sheets 6-7
6.3.8 Media Communications 6-8

6.4 Conclusion 6-8

SECTION 7 CONCLUSIONS 7-1

7.1 General 7-1

7.1.1 Drainage Relationships 7-2
7.1.2 Irrigation Practices and Emerging Technologies 7-2
7.1.3 Institutional Changes and Economic Incentives 7-4
7.1.4 Information and Education Requirements 7-6

7.2 Summary 7-7

REFERENCES R-1

SECTION 1

EXECUTIVE SUMMARY

FOREWORD

The Agricultural Water Management Subcommittee has been charged by the San Joaquin Valley Drainage Program to prepare a preliminary report addressing on-farm water management alternatives available to effectively reduce agricultural drainage water volumes in the western San Joaquin Valley. Members of the subcommittee and other contributors jointly produced this report.

PURPOSE

The subcommittee's report is intended to be used by the San Joaquin Valley Drainage Program, water resource professionals, and others as a preliminary guide for establishment of an action plan to reduce drainage water volumes in the western San Joaquin Valley. Drainage reduction and on-farm water management will be major elements in the solutions that are proposed to manage the drainage problem.

OVERVIEW

Agricultural lands on the west side of the San Joaquin Valley between the Buena Vista Lake bottom in Kern County and Tracy in San Joaquin County are becoming increasingly impacted by rising shallow water table conditions. This is the result of natural geological features, native soil salinity, and long-term irrigation (Figure 1.1).

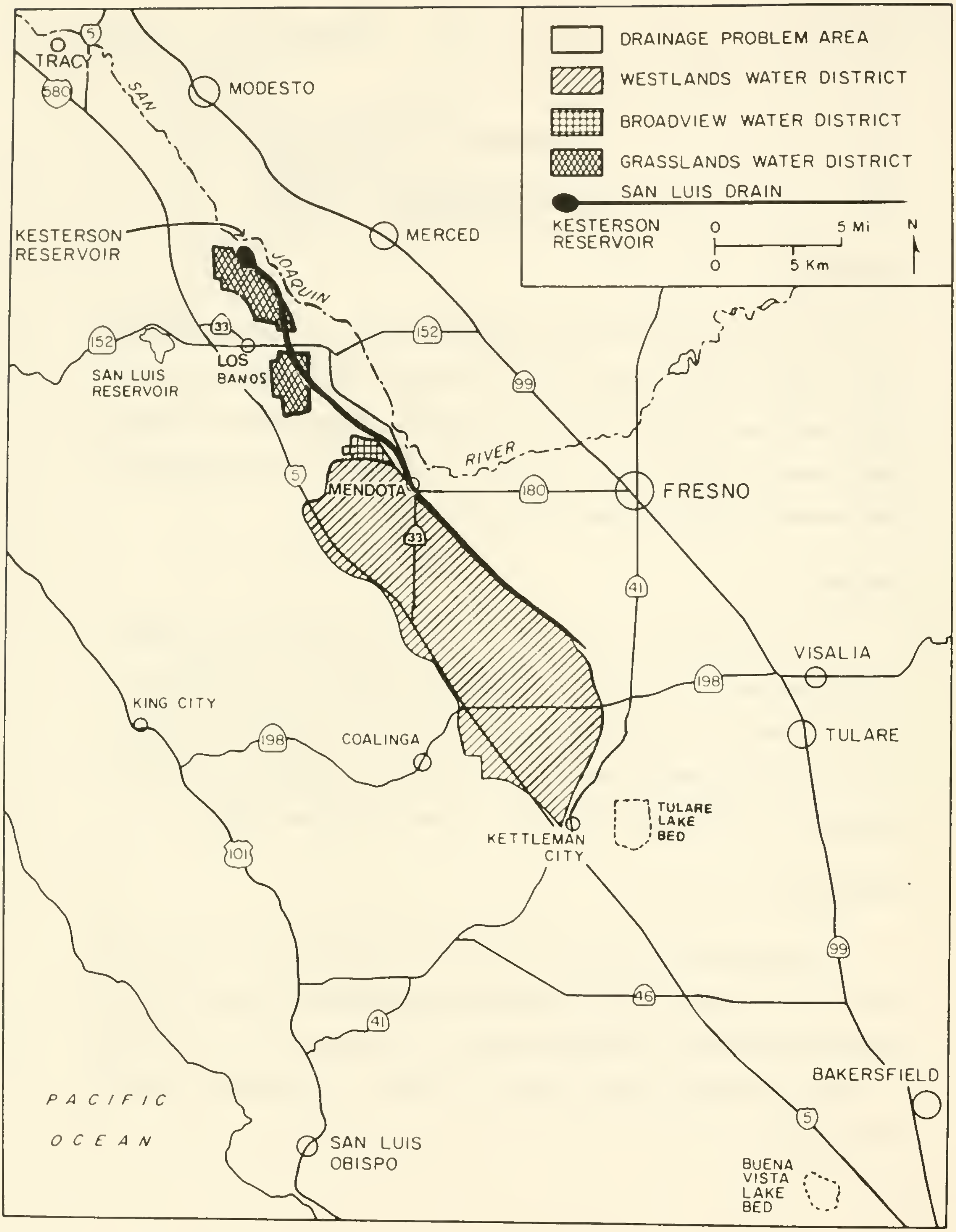

Figure 1.1 San Joaquin Valley problem drainage area, 1985.

A master drain was part of an early plan to remove drainage waters from the valley by paralleling the San Joaquin River to the Delta. Eventually the San Luis Drain part of the San Luis Project was built from Five Points in Fresno County to Kesterson Reservoir in Merced County. Subsurface drainage water from Westlands Water District began entering Kesterson from the San Luis Drain in 1981. Other water districts north of Westlands (in the Grasslands Basin) had been conveying drainage water to Grasslands Water District to maintain waterfowl habitat or draining directly into the San Joaquin River.

Severe waterfowl reproductive abnormalities and mortality were evident at Kesterson by 1983. This was attributed to a naturally occurring trace element, selenium, found in the drainage water. In 1985, the State Water Resources Control Board directed the U. S. Bureau of Reclamation to begin clean-up operations of Kesterson. The Department of Interior elected to close Kesterson and Westlands Water District was told by the Bureau to stop discharging drainage water to Kesterson Reservoir by June 1986 in compliance with the April 3, 1985, agreement with the Secretary of the Interior. In the Grasslands Basin, the State Water Resources Control Board has recommended fairly stringent water quality standards for the river that provide even more regulatory pressure for dealing with drainage water. Meanwhile, growers, districts, agencies, and researchers are working to develop solutions and provide management alternatives to current practices before large areas of the San Joaquin Valley suffer losses as a result of soil salinization and rising water tables.

PROBLEM STATEMENT

The drainage problem, succinctly stated, is that "under existing incentives and technology, the constituent load in drainage water and drainage volume exceed disposal capability."

PRESENT ALTERNATIVES

The analyses and public review necessary to evaluate a full range of alternatives have not yet been completed. Presently it seems that realistic, cost-effective alternatives will center around the following areas:

- improving irrigation techniques and reducing drainage volume;
- treating drainage effluent to remove salts and/or toxic trace elements;
- disposal of remaining effluent by:
  - shallow groundwater management
  - land use changes
  - deep well injection, or
  - evaporation ponds, or
  - combination of the above.

The basic alternatives that will be keystone of any long-term solution are improving the water use efficiency of irrigation techniques and reducing drainage volumes at the source; i.e., on-farm. Unfortunately, because of the complexity of the drainage problem, the size of the area affected, and intense regulatory pressure with ever-tightening timelines, the present infrastructure is inadequate to handle the problem. A regional approach is required if effective actions are to be taken in a timely manner.

COMPONENTS OF DRAINAGE REDUCTION

Actions that could be taken by drainage entities and/or existing water districts to reduce drainage volume include these components:

- modifying existing irrigation practices and implementing emerging technology as possible;

- recommending appropriate institutional changes and economic incentives to water policy makers;
- implementing educational and informational programs; and
- improving the monitoring of applied drainage water quantity and quality and researching methods to reuse shallow groundwater.

PROPOSED ACTIONS

To review the four components listed above, the Agricultural Water Management Subcommittee divided itself into four working groups, each group preparing a list of possible drainage reduction actions proposed for either study or implementation.

The Agricultural Water Management Subcommittee recommends the following actions for implementation. All of the actions are considered to be important for drainage reduction. Due to the diverse nature of these components, not all of them are ranked for implementation in the same manner. An "A, B, C" ranking order is used to indicate importance and the time frames "short, intermediate, and long-term" roughly approximate 0-2, 2-5, and 5-10 years, respectively. The criteria and procedures used in ranking each component will be described within each section to follow. All actions, including those ranked "C," are considered important and should be considered for implementation.

It should be noted that the proposed actions which follow have not been thoroughly reviewed by the full subcommittee. It is the intent of the subcommittee to refine the lists which follow into a comprehensive package of actions that will complement one another and will lead to substantial reductions in drainage volumes on an equitable and economic basis.

Irrigation Practices and Technology

The rankings in this component are based on those practices and technologies that would result in the greatest potential drainage reduction. These are ranked A. There is no attempt to factor in monetary costs and benefits of these actions.

Action	Ranking	Comment
Develop surface and subsurface trickle irrigation systems.	A	Needs intermediate-term research. May be constrained by salt accumulation in the long-term. However, with proper management, salt accumulation should not be a long-term constraint. Economic incentives and education are a necessity for implementation.
Develop modified continuous move sprinkler or low pressure systems.	A	Intermediate-term research is necessary, particularly on foliar salt accumulation. The costs of implementation are high. However, foliar salt damage should not be a concern with most anticipated irrigation waters.

Use periodic move sprinkler systems.	B	Short-term research on diked-furrows is necessary, but implementation costs are low for existing systems.
Sprinkle irrigate for early season and seed germination.	B	Can be implemented almost immediately but needs short-term economic analysis for cost-effectiveness.
Surge irrigation (particularly for early season irrigations).	B	Needs intermediate-term research and demonstration projects to be best adapted to California conditions.
Evaluate existing systems and schedule irrigations.	B	Short-term research is needed on deficit irrigation in early irrigations and an economic analysis of costs and benefits.
Improve distribution uniformity of furrow systems using a combination of methods.	B	Short-term to intermediate-term research and demonstration are necessary to improve modeling and compare various combinations.

Irrigate using diluted drainage water.	B	Short- to intermediate-term research needed to improve irrigation scheduling using perched water tables and to evaluate costs and benefits.
Relevel fields to establish uniform grade.	C	Can be implemented immediately but is already a common practice on most fields.
Develop controlled volume irrigation in sloping furrows.	C	Needs intermediate-term research and demonstration for design, economics, and management.
Cablegation on appropriate sites.	C	Needs short-term economic analysis to determine the costs and benefits of this method.
Level basin irrigation on appropriate sites.	C	Needs short-term research on modeling and design for California soils and economic analysis to determine the costs and benefits of this method (limited to very level areas).

Institutional Changes and Economic Incentives

The actions in this component are ranked giving the most weight to two criteria:

1. The need to address due to public concern.
2. The effectiveness of the action in reducing drainage.

In this ranking, "A" rates high in these two criteria, while "C" rates lower.

Action	Ranking	Comment
Evaluate water marketing.	A	Limited marketing may occur in the short-term; but large scale markets are possible only in the long-term due to existing contracts, third-party effects, and local resistance. Would require state and federal action.
Consider land use changes.	A	Small tracts of land may be changed to different land uses such as agroforestry or wildlife habitat in the intermediate-term, but larger tracts wouldn't change until the long-term.

Provide cost-sharing incentives to growers.	A	Some resistance to subsidies, but some small-scale cost-sharing programs already exist. Larger scale of funding needed in the intermediate-term.
Use block/tiered pricing.	A	Flexibility in annual water orders from wholesalers has to occur first. Farmer resistance will occur. Could be implemented in the intermediate-term.
Provide flexibility in annual water orders.	B	Contract changes would be necessary to allow rebates for unused water but could be implemented in the intermediate-term.
Form drainage entities.	B	This is being discussed by agencies at all levels, but there is some local resistance and this action will not conserve water or reduce drainage volumes by itself.
Promulgate regulations.	B	Is being implemented at the state and federal levels, but there is resistance at the local level.

Change the water year.	C	Can be implemented in the short-term and has been accomplished in the federal service area but not, as yet, in the state service area.
Improve flexibility of water deliveries.	C	Currently, water can be ordered 24 hours in advance and terminated at the convenience of the grower in many water districts. Further refinements will be long-term. Increased flexibility in deliveries from districts (frequency, rate, and duration) will be required to reach optimum irrigation efficiencies.

Drainage Relationships

The rankings in this component are the priorities for implementation with "A plus" being the highest and "C," the lowest.

Action	Ranking	Comment
Monitor and evaluate soil salinities, water table levels, and drain flow volume and quality.	A plus	Standardized methodologies for these activities must be adopted and monitoring programs initiated over the long-term. This will provide the basic factual data without which informed decisions cannot be made.
Develop load-flow relationships for salts, boron, selenium, and molybdenum.	A	Load-flow relationships must be known to accurately predict the consequences of potential drainage reduction measures over the long-term.
Recycle drain water for irrigation.	A	Feasibility of this technique has been demonstrated. Education efforts will be needed. This has high potential for reducing drainage volumes beginning in the intermediate-term.

Manage shallow water tables rather than draining to a specified depth.	A	Includes adjusting irrigation regimes to account for crops using shallow water tables by modifying existing drainage systems or introducing new drainage system designs. The potential for drainage reduction is high; but research, demonstrations, and education efforts will be necessary in the long-term.
Use agroforestry and new crops for agricultural production.	B	Research requirements are high, but the potential for new crops to reduce drainage volumes is higher than for the shift towards existing salt-tolerant crops over the long-term.
Use greater amounts of existing salt-tolerant crops. ˙	C	This can be implemented and already is in the short-term, but the potential for drainage reduction is not as great as with new crops.

Discharge drainage volumes intermittently.	C	Timing discharge to coincide with periods of high surface water runoff may facilitate water quality management but not reduce drainage volumes. This technique could be implemented in the intermediate-term.

Education and Information Programs

This component also uses a ranking which denotes priorities for the development of action plans. Items ranked "A" are highest priority and "C," the lowest. Almost all the items ranked "A" and "B" are implementable in the short-term.

Action	Ranking	Comment
Develop "action teams" to educate local districts and growers about drainage reduction practices and programs. Make on-farm visits.	A	These teams would consist of those persons having appropriate agricultural and technical backgrounds for credibility with growers and agricultural water districts. Funding could be provided on a cost-sharing basis from state and local sources. Initial organization of the "teams" may be provided by a "Land-Preservation-Association"-type of entity.

Develop information about growers in high water table areas.	A	An analysis of the various management concerns and capabilities of growers is necessary to design an array of programs most growers would find acceptable.
Develop materials to support "action teams."	A	The action teams will need written materials for the growers and irrigation districts. A newsletter on drainage reduction should also be produced to keep growers informed.
Carry out drainage reduction workshops for growers.	B	Can and is being implemented at present, but the effectiveness of this approach versus a personal on-farm visit should be evaluated.
Establish a public relations program to educate the general public in some of the good water management practices currently being used in the San Joaquin Valley.	B	The public must be informed of and understand all the actions that are and will be taken to improve the agricultural drainage problem.

Promote realistic large-scale, on-farm demonstrations.	C	Demonstration projects in the intermediate-term need to be designed and promoted in a manner that would highlight costs and benefits of alternative irrigation technologies to a typical farming operation, and the capabilities of a farm to adopt it into its operational practices.
Expand exiting irrigation system evaluation programs. Expand use of DWR's Mobile Labs on a regional basis.	C	This would be an intermediate-term effort that could be linked to the "action team" concept.

ECONOMIC IMPACTS

The economic impacts of instituting these actions have not been calculated. For some of the above components, many of the actions do not entail capital costs or costs to growers. On-farm and program costs of the measures identified in this report will be evaluated and documented by the Agricultural Water Management Subcommittee in the future.

SOURCES OF FUNDING

Funding sources for implementation of the report recommendations have not been investigated because of tight timelines for report preparation. Sources that should be investigated are water districts at lower elevations directly impacted by drainage problems and those at higher elevations that are only marginally impacted; California Department of Water Resources; State Water Resources Control Board; and the U. S. Bureau of Reclamation. These entities may be able to provide the funding needed to initiate and sustain a proposed program of this magnitude.

RECOMMENDED CONTINUING ROLE OF THE AGRICULTURAL WATER MANAGEMENT SUBCOMMITTEE

1. That the Agricultural Water Management Subcommittee develop an Action Plan for the implementation of the drainage reduction measures identified in this report.
2. That the subcommittee identify for the San Joaquin Valley Drainage Program Interagency Technical Advisory Committee research, demonstration, and implementation needs identified in this report and in the upcoming Action Plan for Drainage Reduction.
3. That the subcommittee recommend implementation of certain drainage reduction measures that are within the purview of individual member agencies of the subcommittee.
4. That the subcommittee study and recommend legislative and policy initiatives to further the goal of drainage reduction.

SUMMARY

California faces a major challenge as it moves forward to manage the drainage problem. Drainage reduction will be a key element in any solution to effectively manage this problem.

SECTION 2

STATEMENT OF THE PROBLEM

2.1 GEOLOGY

The unique geology of the Coast Range of California, the Sierra Nevada Range, and the San Joaquin Valley (SJV) helps to explain why the localized area is experiencing the current ongoing salinization process and why it has only recently been discovered that the natural trace element selenium (Se) caused wildlife death and mutations in the Kesterson Reservoir (J. Letey, 1987).

Marine sediments were deposited when the area west of the present Sierra Nevada Range was an ancient sea. The sediments contained chemical and organic materials typical of salt water environments. When these sediments were subsequently uplifted forming the present Coast Range, they became the parent material for alluvial deposits that worked slowly downslope toward the trough of the valley marked by the San Joaquin River.

The Coast Range sediments are very fine in texture as contrasted with the coarser textures of the material deposited from the Sierra Nevada Range. Present soils on the east side of the San Joaquin Valley are relatively free of salts and trace elements, whereas west side soils contain large amounts of soluble salts and trace elements.

Geology also explains the layering feature of San Joaquin Valley sediments. These ancient sediments, in many layers, are slowly permeable to water. The largest of these, the Corcoran Clay layer, lies between 400 to 600 feet below the valley floor. Various other clay layers, none as extensive or as consistent, are located above the Corcoran Clay. The complexity of the "underground plumbing" and many localized features make examination and prediction of subsurface water flow and resulting chemical effects costly and time consuming.

Another important geological feature is that, during the deposition of west side and basin trough sediments, the fine-textured clay materials were transported toward the center of the valley, closer to the river, whereas coarser-textured materials were deposited farther upslope. The low-lying, fine-textured soils are where the first symptoms of excess water and salinity were observed.

2.2 IRRIGATION AND SALINIZATION

Irrigation of agricultural lands adds salt to the soil and mobilizes naturally occurring salts. If provisions are not made to manage the amount of water applied and remove subsurface drainage, the soils will gradually lose productivity because of a buildup of salts in the root zone and an increasingly high saline water table. This salinization process has been the proximate cause of the failure of irrigated agriculture from ancient times until the present day.

The geology of the San Joaquin Valley with its numerous, impermeable clay layers only hastens the process. In spite of the fact that imported irrigation water is relatively pure, i.e., low in salt content, the salinization process is relentless. Either the subsurface drainage water and excess salts are removed from the root zone or the land goes out of production and the resulting social and economic infrastructure crumbles.

State and federal water leaders recognized the need to remove subsurface drainage water from the San Joaquin Valley if agricultural productivity were to continue and the region's economic contribution to the state were to be maintained. The solution to this need was thought to be the valley "master drain" which would be built ultimately from Kern County north, paralleling the valley's natural drainage outlet, up to the Delta, where the drainage water would be disposed in the ultimate salt disposal area, the ocean.

The San Luis Drain, authorized to serve the federal San Luis Unit, of the Central Valley Project was to be constructed by the U.S. Bureau of Reclamation (USBR) from Kettleman City and terminate in the Delta. By 1975, when construction was halted due to environmental concerns about drainage water constituents and a shortage of funding, the drain had been built from Five Points to Kesterson Reservoir. The reservoir was intended and designed as a regulatory facility, not as a drainage disposal site, which it became.

2.3 TOXIC ELEMENTS

The sedimentary rocks of the Coast Range bordering the San Joaquin Valley contain a wide variety of natural elements that could be toxic to plants and animals: selenium, chromium, molybdenum, arsenic, boron, lead, mercury, and others. All of these elements, including selenium, are transported into the alluvial soils of the valley by natural, albeit very low, precipitation and stream flow from the coast ranges. Irrigation water imported into the valley has created a general saturation of the overlying Corcoran Clay so that high saline water table conditions exist in root zones. Attempts are made to remove these waters by subsurface tile drains. Because many of these potentially toxic elements or their compounds are soluble, they are present in groundwater removed by subsurface drainage systems.

The potential of the water-soluble, naturally occurring toxic elements to cause toxicity problems for animals varies greatly. Arsenic, cadmium, lead, and mercury can be harmful to animals. Boron is harmful only to plants. Selenium is actually required in trace amounts by both animals and humans. Only in excess quantities is the element toxic.

Bioaccumulation (the accumulation of selenium in plants and wildlife as the element moves with the food chain to higher order animals) began at Kesterson Reservoir with the retention of subsurface drainage water in 1981. The harmful nature of this bioaccumulation did not become evident until aquatic life and water birds began experiencing deformities in their young, high mortality rates, and severe reproductive inabilities.

Public attention focused on the impact of selenium in the environment and possible, but poorly understood, effects that this could have on people.

The long-standing San Joaquin Valley drainage problem had shifted overnight from one of maintaining agricultural productivity to one of widespread concern about possible toxic contamination of water sources.

2.4 REGULATORY PRESSURE AND TERMINATION OF DRAINAGE SERVICES

An intense three-year legal battle followed the selenium-related discoveries at Kesterson Reservoir. The battle was vastly complicated by both federal and state involvement in the process and nationwide media coverage. Factored into this were overlapping federal and state agency responsibilities. The immediate result was an order from the California State Water Resources Control Board (SWRCB) to the U.S. Bureau of Reclamation to close and clean up Kesterson Reservoir. The Westlands Water District stopped discharging drainage to Kesterson Reservoir in June 1986 as required by the agreement dated April 3, 1985, with the Secretary of the Interior.

Currently no drainage water is entering Kesterson Reservoir. Growers in Westlands and in the Grasslands Basin are attempting to manage drainage water locally. The actions taken to date have produced only temporary answers. Areas on the valley's west side and south of Westlands are also experiencing drainage problems, both with and without comparable selenium concentrations in the drain water. The valley's drainage problems, both economic and environmental, are still present.

2.5 THE SEARCH FOR SOLUTIONS

An intense effort by federal, state, local, and university agencies and departments has been initiated since the Kesterson controversy with the mission of attempting to understand the contamination problem and to develop responsible solutions. These solutions include reduction of drainage water volume by improved irrigation methods, treatment of the remaining drainage water to remove potentially toxic elements, underground disposal, on-farm or regional evaporation ponds, and, finally, after toxins and salts are removed, by export to the San Joaquin River. No one solution will fit all conditions. The solution will be a combination of methods adapted to each area.

2.6 DRAINAGE VOLUME REDUCTION

The single most important problem on the west side of the San Joaquin Valley facing water users, water districts, state and federal water agencies, legislators, and the public is that under existing incentives and technology, drainage load and drainage volume exceed disposal capability. It is imperative that we seek ways of modifying institutional practices and economic incentives to accomplish drainage reduction.

Technical solutions which are developed to deal with drainage will be very capital intensive. The size of the facilities built to implement whichever solutions, or combinations of solutions, are best for a particular area will be dependent on the volume of effluent processed. The incoming drainage influent must be reduced to an acceptable level to minimize capital expenses. Subsurface drainage reduction can only be achieved by modifying existing economic incentives and applying present irrigation technology to existing on-farm water management operations to reduce subsurface drainage effluent significantly.

Aggressive on-farm water management to reduce drainage effluent may be the best short- and intermediate-term method for effectively and responsibly managing the drainage problem.

SECTION 3

DRAINAGE RELATIONSHIPS

3.1 INTRODUCTION

Drainage from agricultural land consists of waters running off the soil surface into open ditches, waters percolating below the crop root zone to underlying aquifers, and waters collected by installed drainage systems. This report, however, will only address the relationships and management of subsurface drainage systems including basic concepts of subsurface drainage; descriptions of the soils, hydrogeology, and probable sources of excess drainage water on the west side of the San Joaquin Valley; and introductions of the data base presently available. The two major issues in drainage that will be discussed in some detail are (1) the relationships between the volume of drainage flow (acre feet of drainage per acre of drained land) and the load or mass of salts (tons of salt per acre foot of drainage water) or potentially toxic minor elements like selenium (pounds of Se per acre foot of drainage water) and (2) the options for managing shallow groundwater to minimize drainage flow while sustaining irrigated agriculture. Both topics are vital to resolving the drainage problem on the west side.

Drainage volume could be reduced significantly if (1) drainage effluent could be used as a source of irrigation water to grow alternate and/or salt tolerant crops or (2) the elevation of the shallow groundwater could be managed to permit crops like cotton, sugar beet, safflower, and alfalfa to obtain a portion of their water requirements from the goundwater rather than from irrigation water. Obviously, any strategies that reduce drainage effluent are extremely beneficial both environmentally and economically.

If strategies are developed to reduce drainage volume, the question arises as to what happens to the load of salts or constituents in the reduced drainage volume. Thus, a major portion of this section addresses the relationships between drainage flow and load relationships.

The section concludes with recommendations for research and monitoring. Although a great deal of effort is underway to monitor drain discharge volume and constituents and to measure the elevation of the shallow water table in the problem area, there are still gaps in the data base. Research that is required to determine the drain load-flow relationships operative in the problem area has a high priority as well as testing of water table management strategies.

3.2 BACKGROUND

3.2.1 Drainage Basics

Irrigated agriculture requires water applications beyond crop water needs (evapotranspiration) to maintain a salt concentration of the crop root zone within acceptable levels. Where natural drainage is insufficient to dispose of the salty water draining below the root zone, artificial drains must be installed. Design criteria for such systems should keep the water table low enough to (1) provide an aerated root zone, (2) minimize evaporation from the water table to prevent a net migration of salt up into the root zone, (3) reduce the elevation of the water table so that soil water capillary forces do not force salts up into the root zone, and (4) provide sufficient drain capacity to remove additional waters applied for leaching or applied as a result of inefficiency or nonuniformity of the irrigation system. To avoid upward movement of saline water from the water table, the depth of drains in irrigated, arid land is generally greater than in humid climates.

The most common drainage system in the western San Joaquin Valley is a network of buried, perforated pipe (tile), often with an envelope of gravel surrounding the pipe. Other types of drainage systems include open ditches, drain wells, and "mole" or "French" drains. Open ditches are used in a few locations in the western San Joaquin Valley along the edge of fields and are frequently spaced about one-half mile apart and are quite deep--up to 15 feet or more. Shallow wells drilled into the water table and pumped to remove drainage water are not used on the west side because of low soil porosity. Mole drains are common in Europe and Canada and are formed by a plow creating a conduit like a mole hole while French drains are gravel-filled conduits in the soil. Neither type of drain is lined and they are not used on the west side because of high maintenance requirements. Because of land values and to avoid inconvenience, subsurface pipe drains (tiles) are normally used for subsurface drainage rather than deep, open ditches. In the western San Joaquin Valley, tile drain depths range from six to nine feet. The distance between subsurface drains--drain spacing--varies depending on crop, soil permeability, and water management practices. In irrigated soils, drain spacing typically varies from 150 to 800 feet; spacings of 200 to 400 feet are common on the west side of the San Joaquin Valley.

In an idealized system (homogeneous soil without a shallow stratum that serves as a water barrier) the water table forms a curved surface reaching its maximum height midway between two neighboring drains, paths of water flowing from midway between drains pass well below the elevation of the drain pipe before entering the drain from below (Figure 3.1). The depth to which water may penetrate before entering the drain is, of course, limited by the depth of a water barrier. The water-transmitting properties of various soil layers will also alter the flow paths.

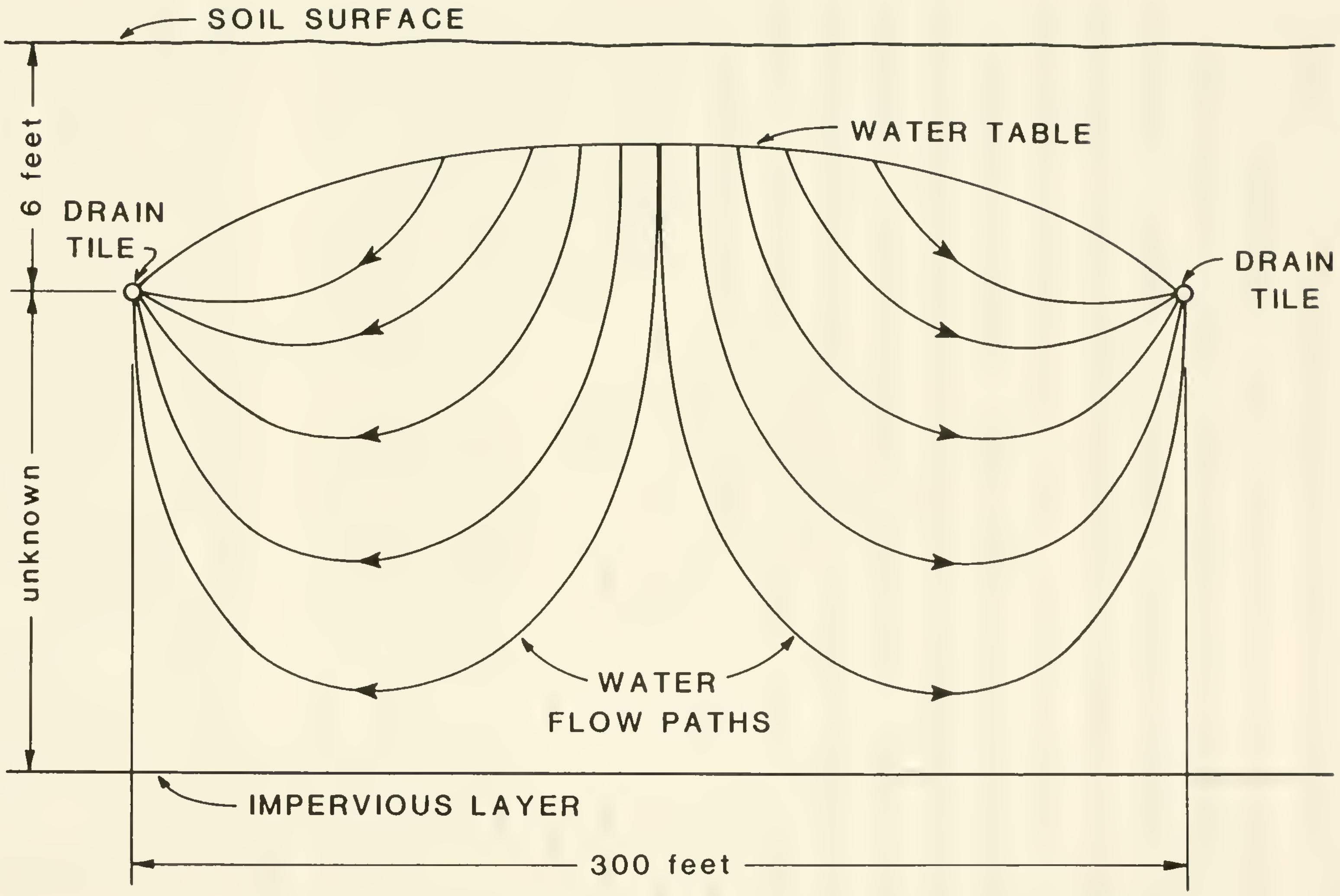

Figure 3.1 Illustration of flow paths to subsurface drains in a homogeneous soil.

Soil layers that restrict water movement will cause the flow paths to be more shallow than for homogeneous soils. Soils in the western San Joaquin Valley are multilayered and water barriers are often found at one or more depths through the soil profile. Few are totally impervious to water movement. Thus, some water moving down through the soil profile may continue its downward movement even in the presence of an artificial drainage system. If natural drainage is sufficient, a shallow water table may not develop. However, if natural drainage is insufficient to accommodate the volume of water passing below the root zone, a water table will form and, in time, may rise into the root zone. Even though a drainage system is installed, natural drainage continues and not all of the water passing below the root zone will be collected in the artificial drainage system.

The area of land drained by an artificial drainage system is typically calculated by multiplying the total length of the drains by the spacing between them. This can be a very conservative estimate of the total land area drained if the system is installed within a region with a shallow water table. Once drainage commences in the field containing the drainage system, water will move from adjacent undrained fields toward the drains. The extent to which the water table is lowered in adjoining areas depends on (1) the capacity of the drainage system to remove water, (2) the water transmitting properties of the soil, (3) the elevation difference between the water table surface and the drains, and (4) the amount of water being replenished to the water table. If replenishment was zero and the region had no irregularities in soil properties, the entire region would eventually be drained. Of course, neither of these simplifying conditions are ever met in the field. One irregularity in soil properties that is common is highly permeable strata. Concentrations of coarse-textured areas in some instances are caused by separation of soil particles by size from the action of wind or water. In many cases, these concentrations have been buried by natural alluvial fan formation or leveling of fields.

Remnants of buried stream channels may contribute to significant movement of water and solutes on the west side.

3.2.2 Soils and Hydrogeology

This is an overview of the geomorphic history and physical/mineral description of the subsurface environment on the west side of the San Joaquin Valley. Specific conditions at any point within the study area are a combination of the conditions described below. There can be wide variability from site to site.

The sedimentary materials of the west-side San Joaquin Valley were deposited over millions of years from the erosion of surrounding mountains. Alluvial fan deposits came from Coast Range materials and valley trough deposits came from a mixture of Sierra Nevada and Coast Range materials. Streams flowing into the valley carried soil particles that settled out in order of their size. The largest particles settled out first, making the relatively light and permeable soils found along the perimeter of the valley floor. The smallest particles were carried farther by the stream flows, into the valley trough, where they formed tighter, less permeable soils. Over time, the valley trough was often covered by large bodies of water. Very fine soil particles in these water bodies settled to the bottom, forming less permeable clay layers. Such layers typically underlie the drainage problem areas at depths ranging from near land surface to about 40 feet. In this area, ground water is typically present within 20 feet of land surface.

Soils derived from the marine sedimentary rocks of the Coast Range predominate in the west side of the valley. These typically contain relatively large amounts of water-soluble mineral salts, as do the parent materials. In many parts of the groundwater reservoir, down to a depth of about 300 feet, the groundwater is also highly mineralized.

There are various interpretations of data relative to the continuity of the subsurface materials and their impedance of groundwater flow. It is known that water levels and potentiometric surfaces vary with depth in the aquifer system. However, the theory of strictly defined aquifer zones is not supported by subsequent data or recent mathematical models.

3.2.3 Sources of Excess Drainage

Precipitation

The west side of the San Joaquin Valley is arid, receiving between 5 and 14 inches of precipitation annually in the southern and northern parts of the valley, respectively. Most rain falls between November and March. Evapotranspiration from cropland averages 29 inches annually in the northern half of the Valley and over 39 inches in the southern half depending on the cropping pattern (Department of Water Resources, 1984). As noted in the Westlands Water Conservation and Management Handbook, only part of the total precipitation is effective in satisfying crop water requirements. The remainder is lost to runoff and evaporation from the soil or leaf surfaces. Approximately one-third of the annual precipitation in the western SJV falls during the growing season. In the Westlands Water District the average effective precipitation under current cropping patterns is 0.1 acre-feet/acre. Some is taken into storage in the soil. Estimates of effective precipitation vary for different crops, cultivation practices and planting dates. An estimate of 0.3 acre-feet/acre was assumed for average effective precipitation for the Grasslands DSA (SWRCB, 1987).

Overirrigation

Irrigation scheduling in many water districts on the west side of the SJV is managed to supply water when available water in the crop root zone has reached a minimum level for optimal crop yield (i.e., the root zone experiences a maximum allowable depletion) (Westlands, 1985). As the season progresses, it becomes increasingly difficult to obtain sufficient infiltration of applied water, to compensate for evapotranspiration losses, using traditional flood and furrow irrigation techniques, because of surface sealing of soils. Growers in some areas apply large quantities of water as pre-plant irrigation to compensate for this problem and to ensure that there is a sufficient reservoir of water available to the crop. The great variability in soil hydraulic properties in some west side soils and management constraints may limit the ability of growers to achieve reductions in percolation to groundwater. Excessive pre-plant irrigation and the first irrigation after planting are responsible for most of the overirrigation that occurs on the west side. Contributions to the shallow groundwater can also result when precipitation closely follows a pre-plant irrigation or when pre-plant irrigation and the first irrigation of the season are closely spaced in time.

Seepage

Source control is one of the most logical management solutions to drainage problems in the western San Joaquin Valley. The success of water conservation techniques is predicated on the assumption that a reduction in deep percolation to groundwater leads to a corresponding reduction in tile flows, in areas where drainage tile has been installed. Seepage flows from conveyance and collector systems, natural water channels, reservoirs, and holding ponds contribute substantial amounts of water to the regional aquifer in some areas and may, in some situations, dwarf the potential effect of water management measures. Quantification of these water fluxes is essential to develop realistic management strategies for drainage water in the long term.

The State Water Resources Control Board has estimated canal seepage losses in their drainage study area at 0.1 acre-feet/acre. This study area includes all of Broadview, Pacheco, and Wildren Water Districts; the Panoche Drainage District, the Firebaugh Canal Company, and seven percent of both the San Luis Water District and the Central California Irrigation District, totalling 94,480 acres. This estimate presumably accounts for the major irrigation conveyance structures as well as on-farm delivery and collector systems.

A groundwater mound has been reported under the California Aqueduct indicating considerable leakage to the groundwater aquifer (Belitz, 1987; SWRCB, 1987). This mound recharges both to the east and west of the aqueduct and is unstable. (SWRCB, 1987) The location of the groundwater divide has the potential to move either side of the canal alignment. Rates of recharge have not been adequately quantified.

The Delta Mendota Canal is earth-lined for 19 miles of its length in the Grasslands sub-basin. Although the USBR (1953) report describes the clay base of the canal as permitting minimal leakage to adjoining cropland, local entities do not share the USBR's confidence.

Natural Water Channels and Springs

Flow in natural channels rarely reaches the San Joaquin River or sloughs tributary to the river in most years. Artesian seeps in the vicinity of the basin trough existed prior to development of groundwater but have largely disappeared with reduction in the piezometric head in the aquifer.

Relic stream beds (stringers) exist in the drainage-impacted area and are thought to account for increased conveyance of water downslope (Jones and Stokes, 1985). These stringers contain sand and gravel materials and, as a consequence, have high hydraulic conductivities--measured values of 26 feet/day have been reported (Jones and Stokes, 1985). The importance of these artifacts as natural drains is diminished by the fact that they do not appear to be continuous across the study area.

Reservoirs and Holding Ponds

Major reservoirs suspected as contributing to the regional groundwater are the San Luis Reservoir and the adjacent O'Neill forebay facility. There appears to be little public information on groundwater recharge from these facilities. Leakage from holding and evaporation ponds in the San Joaquin Valley is largely a function of the base materials of these ponds and pond construction. The U.S. Geological Survey (USGS) conducted a study of directions and rates of groundwater movement in the vicinity of the Kesterson Reservoir (Mandle and Kontis, 1986) and estimated seepage fluxes out of the reservoir between 0.22 and 11.68 feet/year from water budget data.

3.2.4 Data Base

Water Table Elevations

The depth to shallow groundwater is monitored on a quarterly basis by the USBR and California Department of Water Resources (DWR) using a network of wells located in the study area. The elevation of the sub-Corcoran piezometric head is monitored by Westlands Water District, which publishes contour maps of both water table elevations and the depth to shallow groundwater semi-annually and piezometric heads annually.

A regional aquifer study has been undertaken by the USGS with funding from the San Joaquin Valley Drainage Program to model the regional groundwater system. Preliminary results from this study presented at a workshop organized by California State University, Fresno, (CSUF) suggests that irrigation development since 1952 has added a considerable amount of water to the shallow groundwater table west of the Valley trough. The water table is now 20 feet below the soil surface, while in 1950 the water table was about 100 feet deep. In effect, the groundwater reservoir overlaying the Corcoran Clay is largely saturated.

Drainage Quantity and Quality

The Department of Water Resources monitors 38 subsurface drains and two surface drains in the central and southern SJV, in areas roughly delimited by Dos Palos and Mendota and by Hanford and Bakersfield, respectively. Flow, pesticide, and nutrient mineral constituent concentrations are measured at these locations. Since 1984, DWR has increased the frequency of selenium sampling from annual to monthly intervals.

An unpublished report of waste discharge (USBR, 1984) contains estimates of drainage quantities and qualities for the San Luis Unit and Delta Mendota service areas. This study assumed a rate of drainage installation in the service area that would meet demand for drain discharge and achieve salt balance between 1995 and 2020. Salinity, nitrate, boron and 13 trace elements were considered in the study. Results of the analysis showed that the salt content of the drain water might average 7,000 mg/l in the San Luis service area and 3,500 mg/l in the Delta Mendota service area north of Dos Palos during the first 25 years of drainage installation. Selenium was not included in the analysis.

Data on the concentrations of constituents in the shallow groundwater of the San Luis Drainage Study Area (DSA) including salt and selenium are best summarized in Deverel, et. al. (1984). Field studies by Deverel and Fujii have shown that the highest selenium concentration and salinity levels are the result of concentration by evaporation and evapotranspiration from shallow groundwater. High selenium loads in drainage water have been explained by the displacement of resident saline, high selenium groundwater by less saline irrigation water (Deverel and Fujii, 1987). Current and ongoing field and modeling studies are helping to expand the current database to improve present understanding of this process. It is likely that under high water table conditions, flow lines that penetrate tens of feet into the ground are forcing into drain tiles salts and toxicants put there during geologic time or by initial leaching of salts from fields during irrigation.

3.3 DRAIN LOAD-FLOW RELATIONSHIPS

3.3.1 Basic Drain Load-Flow Relationships

Regulation of Agricultural Drainage

To protect the beneficial uses of the San Joaquin River, the San Joaquin River Basin Technical Committee of the SWRCB has recommended interim water quality objectives for several stations in this stream (SWRCB Technical Committee Draft Report, May 1987). The committee has narrowed water quality constituents of concern from a list of 25 to four (salinity, selenium, boron, and molybdenum). The water-quality parameter for salinity is electrical conductivity (EC) in millimhos per cm (dS/m) or in equivalent standard international units of deciSiemens per meter (dS/m). EC is a lumped salinity parameter indicative of salt concentration in the water. The units for other constituents of concern are given in terms of micrograms per liter (ug/L) or parts per billion (ppb).

Note that these water-quality constituents of concern are expressed in concentration units because impacts to beneficial uses of water are in terms of concentration. In contrast, for the proposed regulation of agricultural drainage waters, the Technical Committee uses concentration units as well as load (mass); i.e., product of concentration of a quality constituent and the volume of water. Moreover, implicit in the evaluation for proposed regulation is the so-called "Load-Flow" relationship.

This section explains "Load-Flow" relationship by defining water volume and flow and addressing basic concepts and principles involving concentration-volume-mass interrelationships and salt balance in the crop root zone.

Water Volume and Water Flow

Figure 3.2 shows the major water components and water-flow pathways in the crop root zone of irrigated lands. Although agricultural drainage water consists of surface runoff and drainage below the root zone, this section will not consider surface runoff. In this simplified figure, subsurface drainage is split into deep percolation to water-bearing substrata and collected subsurface drainage. The latter includes effluents from tile drainage systems and interception of subsurface waters by open channel drains and natural drainage channels. Not shown are lateral flow of subsurface water into and out of the root zone, nor the rise and fall of shallow groundwater relative to the crop root zone. Hereafter, collected subsurface drainage will be referred to as drainage.

Measurements of water are either water volume, such as acre-feet, or water flow, such as cubic feet per second and acre-feet per 24 hours. Note that units of water flow are stated as volume per unit time. Applied irrigation waters and drainage are often evaluated in terms of volume per unit area over a given time period (year, irrigation season), for example, acre-feet per acre (or surface depth in feet) for the 1987 irrigation season.

Concentration-Volume-Mass Relationships of Constituents

The mass of constituents in waters (trace elements or dissolved mineral salts) is defined as the product of concentration of the chemical and volume of water.

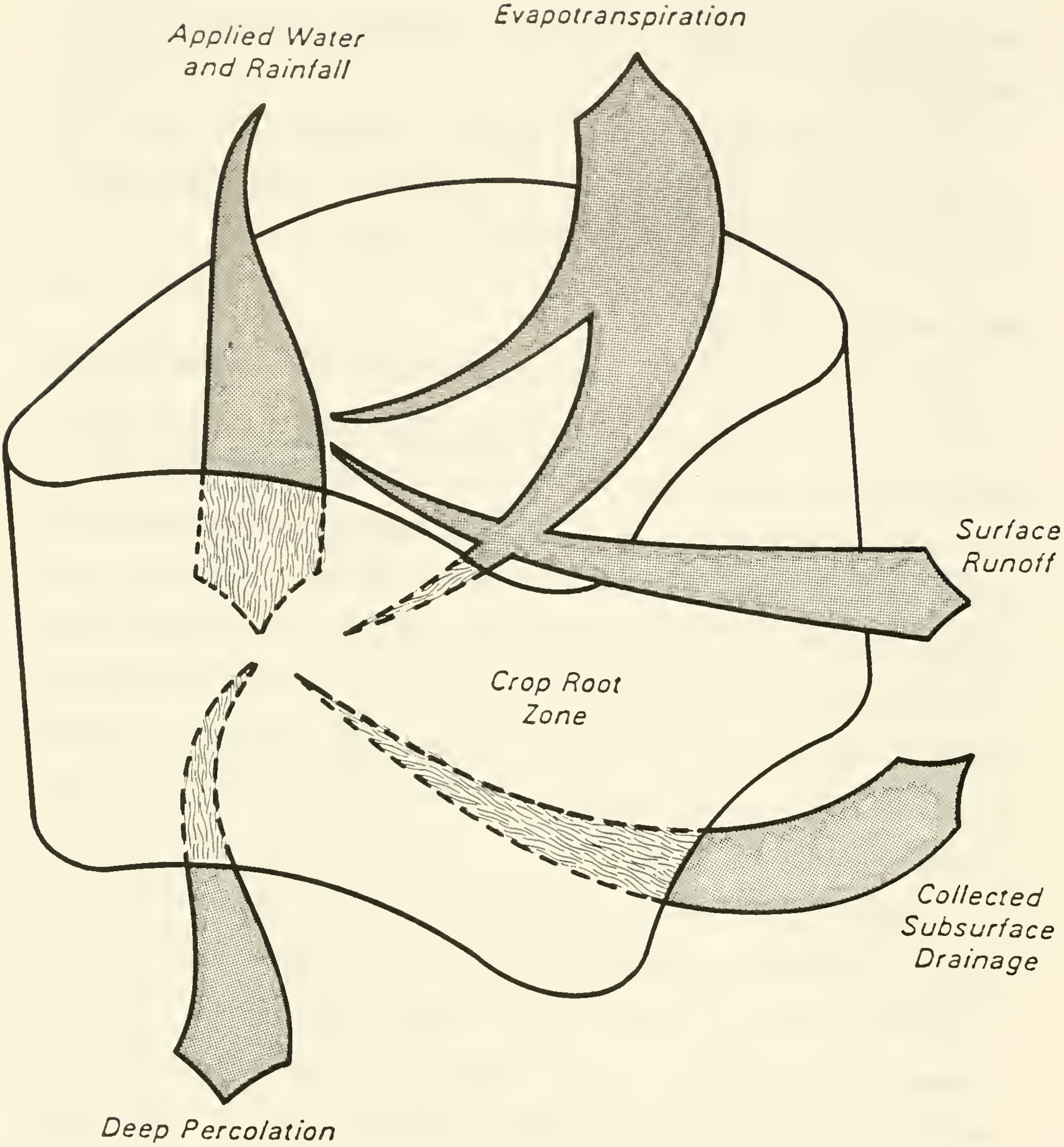

Figure 3.2 The major water-flow pathways in the root zone portions of irrigated lands.

The salinity parameter used by the Technical Committee is EC, which is an intensive parameter. In contrast, Total Dissolved Solids (TDS), another lumped salinity parameter, is an extensive parameter, having concentration units of milligrams per liter (mg/L) or parts per million (ppm). TDS may be estimated from EC by multiplying EC (dS/m) by a factor ranging from 615 (Technical Committee) to 800 (Westlands Water District). For the following illustrative examples, a factor of 640 will be used. Tons of dissolved mineral salts in an acre-foot of water is calculated by multiplying the mg/L TDS by 0.00136 or by multiplying dS/m by 0.8704 (i.e., 640 x 0.00136).

The committee uses ppb as the concentration unit for selenium, boron, and molybdenum. Pounds of trace element in an acre-foot of water is obtained by multiplying ppb by 0.00272.

If we assume that the chemical is conservative, it neither decays nor grows with change in water volume, then the mass of the chemical in a body of water remains constant. For instance, if EC of the irrigation water is 0.55 dS/m, and there are 3 ac-ft of water, the mass of salts is:

$$\text{Tons Salt} = (0.55 \text{ dS/m} \times 640 \times 0.00136)(3 \text{ ac-ft})$$

$$\text{Tons Salt} = 1.44$$

Now, if we assume that 3 ac-ft of water is concentrated in volume by evapotranspiration (ET) to 40% of its original volume, or 1.2 ac-ft, and salinity is assumed to be conservative, the EC of this concentrated water is:

$$\text{EC} = \frac{1.44 \text{ tons}}{640 \times 0.00136 \times 1.2 \text{ ac-ft}} = 1.38 \text{ dS/m}$$

Thus, as water volume is reduced, EC increases in direct proportion, if it is assumed to be a conservative parameter, and vice versa.

Salt Balance in Crop Root Zone

The mass balance of salts in the root zone is defined as:

Salt Mass in Inflow - Mass of Salt Sinks + Mass of
Salt Sources = Salt Mass in Outflow

which will be abbreviated to

$$M_{iw} - M_{si} + M_{so} = M_{dw}$$

where subscript iw denotes irrigation water, dw is drainage water, si is salt sinks (such as mineral precipitation and plant uptake of salts) and so represents salt sources (such as mineral dissolution, lateral subsurface flow, and rising groundwater). Recall that mass M is the product of concentration and volume, so that

$$C_{iw}V_{iw} - M_{si} + M_{so} = C_{dw}V_{dw}$$

Case 1: If we assume that M_{si} and M_{so} are negligible and/or cancel each other out, then

$$C_{iw}V_{iw} = C_{dw}V_{dw}$$

Taking the same case problem as above but using mg/L TDS for salt concentration instead of EC, C_{iw} is

$$\text{mg/L TDS} = 0.55 \text{ dS/m} \times 640 = 352$$

Expressing V_{iw} and V_{dw} in terms of unit depth; (i.e., ac-ft/ac), the salt concentration of the drainage water would be

$$C_{dw} = \frac{C_{iw}V_{iw}}{V_{dw}} = \frac{(352\ \text{mg/L})\ (0.00136)\ (3.0\ \text{ac-ft/ac})}{(1.2\ \text{ac-ft/ac})} = 1.20\ \text{tons/ac-ft or}\ 880\ \text{mg/L}$$

The salt concentration in mg/L TDS is found by dividing tons/ac-ft by 0.00136. The results for this and the following examples are summarized in Table 3.1.

Case 2: Now, if we assume that a portion of the dissolved mineral salts in the applied irrigation water concentrated by ET (1.8 ac-ft/ac) results in mineral precipitation in the root zone, the mass of dissolved salts would decrease in the drainage water. If 20% of the salts in the applied water precipitates out in the root zone, then the mass of salt sink would be

$$M_{si} = (352\ \text{mg/L})\ (3.0\ \text{ac-ft/ac})\ (0.00136)\ (0.2) = 0.29\ \text{tons/ac},$$

and the mass of salts in drainage water would be,

$$M_{dw} = M_{iw} - M_{si}$$

$$M_{dw} = (352\ \text{mg/L})(3.0\ \text{ac-ft/ac})(0.00136) - (0.29\ \text{tons/ac}) = 1.15\ \text{tons/ac},$$

and the concentration of salts in the drainage water would be

$$C_{dw} = \frac{C_{iw}V_{iw} - M_{si}}{V_{dw}}$$

$$C_{dw} = \frac{(352\ \text{mg/L})\ (3.0\ \text{ac-ft/ac})\ (0.00136) - (0.29\ \text{tons/ac})}{1.2\ \text{ac-ft}}$$

$$C_{dw} = 0.96\ \text{tons/ac-ft or}\ 706\ \text{mg/L TDS}$$

Therefore, a 20% precipitation in the root zone of dissolved mineral salts--such as calcium carbonate ($CaCO_3$)--from the applied irrigation water results in 706 mg/L

TABLE 3-1

Illustrative Salt Balance Computations

Description	Case 1: No Mineral Precipitation or Dissolution	Case 2: Mineral Precipitation Only	Case 3: Mineral Precipitation & Dissolution	Case 4: Mineral Precipitation & Dissolution, & Decrease in Drainage
Irrigation Water:				
Unit Depth, ac-ft/ac	3.00	3.00	3.00	2.40
Salt Concentration, mg/L TDS	352	352	352	352
Salt Mass, tons/ac	1.44	1.44	1.44	1.15
Salt Sink in Root Zone:				
Salt Mass, tons/ac	0	0.29	0.29	0.34
Salt Source in Root Zone				
Salt Mass, tons/ac	0	0	4.29	2.15
Drainage Water:				
Unit Depth, ac-ft-ac	1.20	1.20	1.20	0.60
Leaching Fraction, drainage/irrigation	0.40	0.40	0.40	0.25
Salt Mass, tons/ac	1.44	1.15	5.44	2.96
Salt Concentration, tons/ac-ft	1.20	0.96	4.53	4.93
Salt Concentration, mg/L TDS	880	706	3,331	3,627

TDS in the drainage water, instead of 880 mg/L TDS, when mineral precipitation does not occur.

Case 3: Let us now take an example of mineral dissolution; e.g., gypsum ($CaSO_4 \cdot 2H_2O$) which is prevalent in west-side soils. Assuming that the solubility of gypsum in the soil is 2,630 mg/L, the mass of gypsum dissolved in the drainage water is

$$M_{so} = (2{,}630\ \text{mg/L})\ (1.2\ \text{ac-ft/ac})\ (0.00136) = 4.29\ \text{tons/ac}$$

The mass of salts in the drainage water is

$$M_{dw} = M_{iw} - M_{si} + M_{so}$$

$$M_{dw} = (1.44\ \text{tons/ac}) - (0.29\ \text{tons/ac}) + (4.29\ \text{tons/ac}) = 5.44\ \text{tons/ac}$$

The concentration of salts in the drainage water is obtained from

$$C_{dw} = \frac{M_{iw} - M_{si} + M_{so}}{V_{dw}}$$

$$C_{dw} = \frac{(1.44\ \text{tons/ac}) - (0.29\ \text{tons/ac}) + (4.29\ \text{tons/ac})}{1.2\ \text{ac-ft/ac}}$$

$$C_{dw} = 4.53\ \text{tons/ac-ft or } 3{,}331\ \text{mg/L TDS}$$

The presence of gypsum in soils and its dissolution in the drainage water have increased the TDS of the drainage from 880 mg/L, assuming no mineral precipitation and dissolution, to 3,331 mg/L! Clearly, gypsum is a major source of salts in waters drained from crop root zones containing soil gypsum.

Case 4: Drainage water production from the root zone in the three previous cases, was assumed to be 1.2 ac-ft and applied water, 3.0 ac-ft. The leaching fraction (LF) for these three cases is

$$LF = \frac{V_{dw}}{V_{iw}} = \frac{1.2 \text{ ac-ft/ac}}{3.0 \text{ ac-ft/ac}} = 0.4$$

i.e., 40% of the applied water is drained out of the root zone.

Let us now take a fourth case in which the applied water is arbitrarily reduced by 20%, to 2.4 ac-ft/ac. The salt mass in the applied water is

$$M_{iw} = (352 \text{ mg/L TDS}) (0.00136)(2.4 \text{ ac-ft/ac}) = 1.15 \text{ tons/ac}$$

Assuming that ET remains the same (1.8 ac-ft/ac), then the LF is 0.25 (0.6 ac-ft/ac ÷ 2.4 ac-ft/ac).

When LF is lowered, mineral precipitation in the root zone tends to increase. Conversely, when LF is raised, mineral dissolution would tend to increase. Let us assume that mineral precipitation increased from 20 to 30% of the salt mass in the applied water as LF is decreased from 0.4 to 0.25. The mass of salts in this salt sink is

$$M_{si} = (M_{iw}) (0.3) = (1.15 \text{ tons/ac}) (0.3) = 0.34 \text{ tons/ac}$$

The amount of mineral (gypsum) dissolution will decrease since drainage has decreased from 1.2 to 0.6 ac-ft/ac,

$$M_{so} = (2{,}630 \text{ mg/L TDS}) (0.6 \text{ ac-ft/ac}) (0.00136) = 2.15 \text{ tons/ac}$$

The mass of salts in the drainage water is

$$M_{dw} = M_{iw} - M_{si} + M_{so}$$

$$Mdw = (1.15 \text{ tons/ac}) - (0.34 \text{ tons/ac}) + (2.15 \text{ tons/ac}) = 2.96 \text{ tons/ac}$$

and the concentration of salts in the drainage water is

$$C_{dw} = \frac{M_{iw} - M_{si} + M_{so}}{V_{dw}}$$

$$Cdw = \frac{(1.15 \text{ tons/ac}) - (0.34 \text{ tons/ac}) + (2.15 \text{ tons/ac})}{0.6 \text{ ac-ft/ac}}$$

$$Cdw = 4.93 \text{ tons/ac-ft or } 3{,}627 \text{ mg/L TDS}$$

Case 4 illustrates that a 50% reduction (from 1.2 to 0.6 ac-ft/ac) in drainage water production from the crop root zone resulted in a 46% reduction in salt mass as compared with Case 3 (5.44 - 2.96 tons/ac ÷ 5.44 tons/ac), and slightly greater salt concentration (3,627 vs. 3,331 mg/L TDS) than with Case 3. Case 4 clearly points out that one option in reducing the salt load in drainage waters from crop root zone containing soil gypsum is to reduce the volume of drainage water.

If, however, soil gypsum was not present in Case 4 and there was 30% precipitation of salts in the root zone, the salt mass in the drainage water would be 0.81 tons/ac and the salt concentration, 993 mg/L TDS. Case 4 without soil gypsum--but with mineral precipitation--may be compared to Case 2, which had a higher LF (0.4 vs. 0.25). A comparison between the two indicates that salt mass in the drainage water of the former is 30% less than of the latter (0.81 vs. 1.15 tons/ac) while TDS in the former is 140% greater than in the latter (993 vs. 706 mg/l). The difference in salt mass between these two is mainly due to greater mineral precipitation at the lower LF.

3.3.2 Preliminary Analyses of Database

Knowledge of the relationships between the amount of agricultural subsurface drain flow and the load (tons per acre drained) or concentration (mg/L, ppb) of salts and selenium is paramount to developing strategies for achieving the water quality objectives for the San Joaquin River. The current assumption is that the salt or selenium concentration of the drainage water is independent of the volume of drainage water. In other words, the relationship between drainage volume and salt or selenium load is linear. If this assumption is valid, then a plausible explanation is that the salt and selenium loads of drain water generated by on-farm irrigation are determined by the chemistry of the shallow groundwater and underlying geologic strata, which has not been affected significantly by current leaching through the root zone from irrigation.

Data were analyzed from the main drainage outlets for both Broadview and Panoche Water Districts and from the 42,000-acre drainage area in Westlands Water District. Information from Westlands was for two main collector drains (drain 129.5, which is 10 miles in total length and runs from west to east about one mile south of Mendota, and drain 136.0, 21 miles in total length and about seven miles south of Mendota) and from the San Luis Drain, which is a composite of all the District's main collector drains.

The relationship between both the selenium concentration and salt concentration, measured as electrical conductivity, and the volume of discharge from the main drain in Panoche Water District during 1985 and 1986 are shown in Figure 3.3. The main drain discharge is a commingling of waters from the tile drainage systems, surface runoff, and district operational spills. The average electrical conductivity of these commingled waters from October 1985 to October 1986 was 3.5 dS/m, and the average selenium concentration was 53 ug/L. Concentrations in the main drain are diluted, particularly during the irrigation season, because the electrical conductivity of the irrigation and runoff waters is about 0.5 dS/m and the selenium concentration is less than 1 ug/L. The proportion of the main Panoche drain discharge that is tile flow was estimated by assuming that monthly distribution for several on-farm drainage systems was applicable to the main drain. The monthly fraction of the total annual subsurface drainage flow varied from about 4% in late fall to 10% or more during the summer. The electrical conductivity of the portion of the main drain discharge that originated from subsurface drains was calculated on a volume-weighted basis to be 6.7 dS/m with a standard deviation of 1.1 and the mean selenium concentration was 110 ug/L with a standard deviation of 20. With these limited data from the main drain of Panoche Water District, it is not possible to draw firm conclusions on the relationship between salt and selenium load and tile discharge.

From data provided by Broadview Water District, the relationships between both salt load and selenium load and the fraction of the discharge from the main drain that comes from subsurface drainage flows are presented in Figure 3.5. To meet contractual quality standards for the drain water to be discharged into Grassland Water District, the subsurface drainage is mingled with irrigation water. For these data, one-fourth of the total drain discharge from the district was assumed to be subsurface drain effluent. The relationship in Figure 3.4, although highly correlated, has a high degree of variability. This may well be caused by the assumption that subsurface drain flow is consistently one-fourth of the main drain discharge. Likewise, selenium load is a function of drain discharge, but a great deal of scatter exists in the data.

Salt load in the San Luis Drain at Mendota as a function of discharge is illustrated in Figure 3.4. The data are monthly means from January 1981 to May 1986 when discharge from Westlands Water District's drainage collector system ceased. The average value of electrical conductivity of the drain water is 11.5 dS/m with a

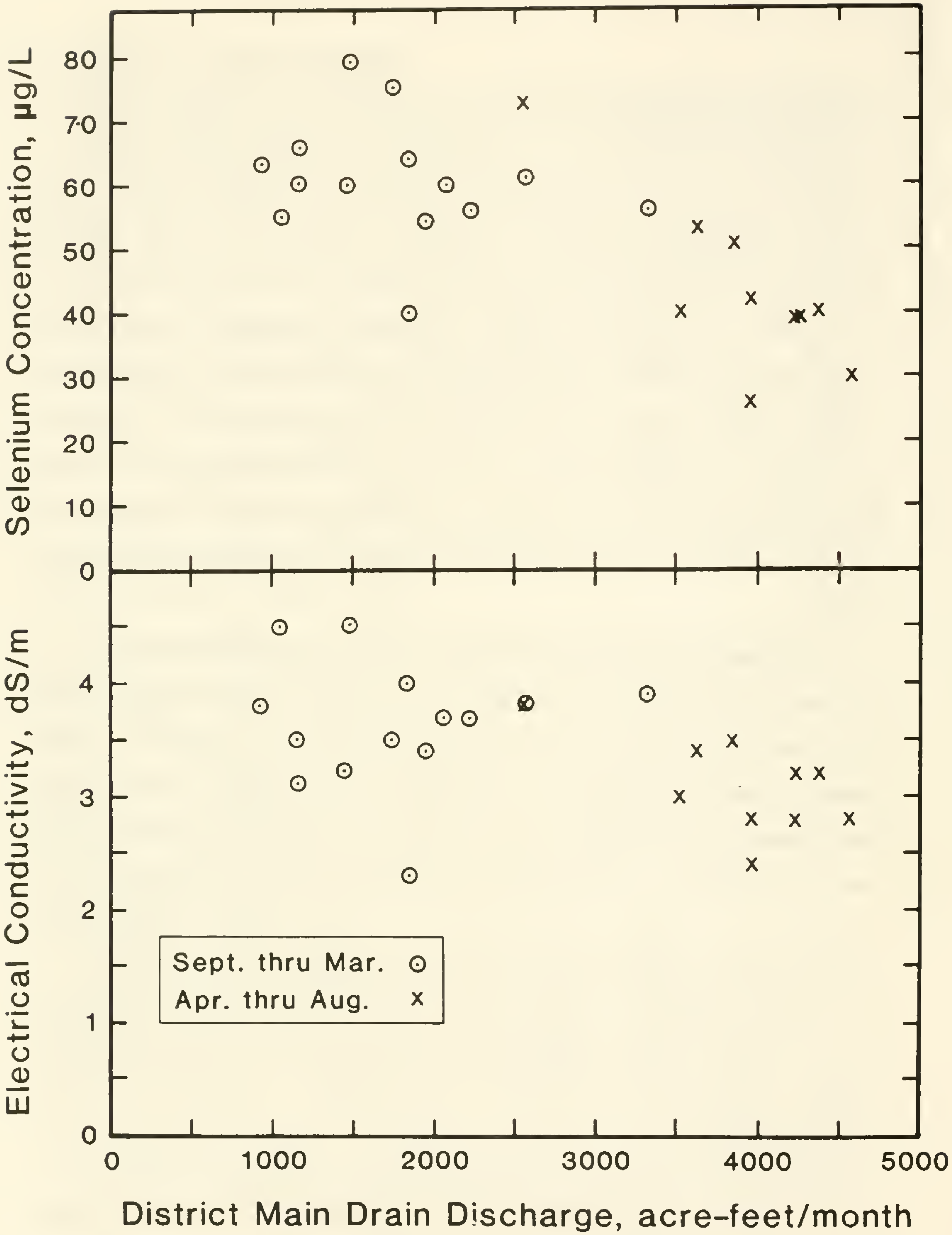

Figure 3.3 Selenium concentration and electrical conductivity as a function of the monthly main drain discharge for Panoche Water District in 1985 and 1986.

standard deviation of only 0.8. The conversion from electrical conductivity to salt load is based upon laboratory analyses of the drain water, which indicated that an electrical conductivity of 1 dS/m equals about 800 mg/L of total dissolved salts (TDS) on the average. The data in Figure 3.5 shows that salt load is a linear function of drain flow. The least-squares linear relationship has an intercept of 400 tons and a slope of 12.5 tons of salt per acre-foot of drain discharge. The correlation coefficient for the linear relationship is 0.98. An analysis of the residuals (predicted minus measured values) indicates that the linear relationship overpredicts at low values of drain flow and underpredicts at high values. This probably indicates that the conversion factor is not constant at 800 mg/L of total dissolved salts per dS/m. This would account for the linear-fit line having an intercept different from zero. These results for the San Luis Drain support the hypothesis that the salt concentration is independent of drain flow and salt load is directly proportional to drain flow.

3.4 MANAGEMENT OF SHALLOW GROUNDWATER

3.4.1 Alternate Crops

Choosing an alternate crop to meet existing salinity or drainage needs may expand the ability of the farmer to cope with drainage water reduction and disposal needs. This review draws heavily upon research work by scientists from USDA, University of California, and other agencies.

All plants do not respond to salinity in a similar manner. There appears to be an eight- to ten-fold range in salt tolerance of agricultural crops, which allows for a greater use of moderately saline water and greatly expands the acceptable range of water use for irrigation. The plant response, however, is not to water salinity but to the level of soil salinity that builds up from use of that water.

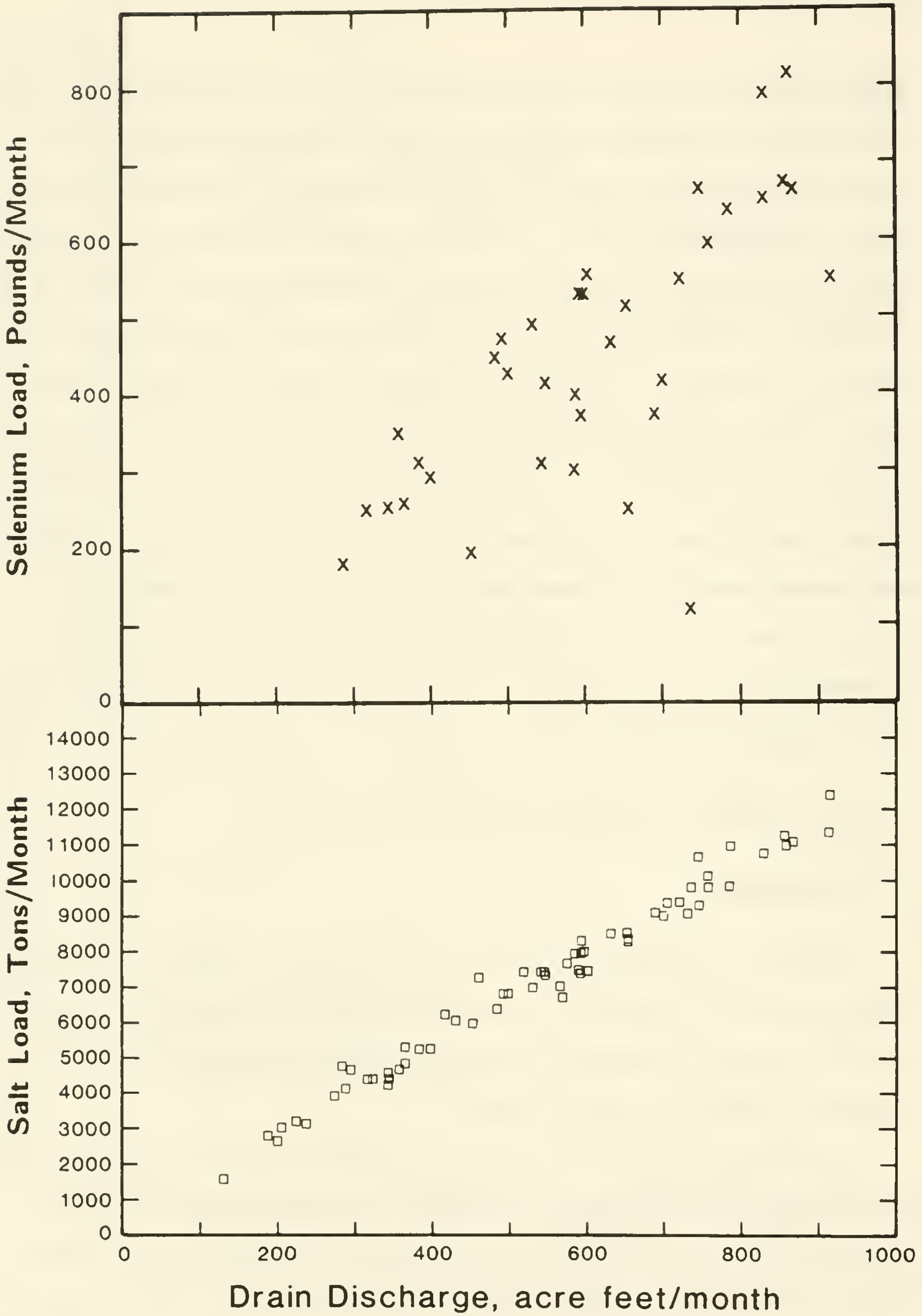

Figure 3.4 Selenium and salt load of San Luis Drain at Mendota as a function of drain discharge from January 1981 to May 1986.

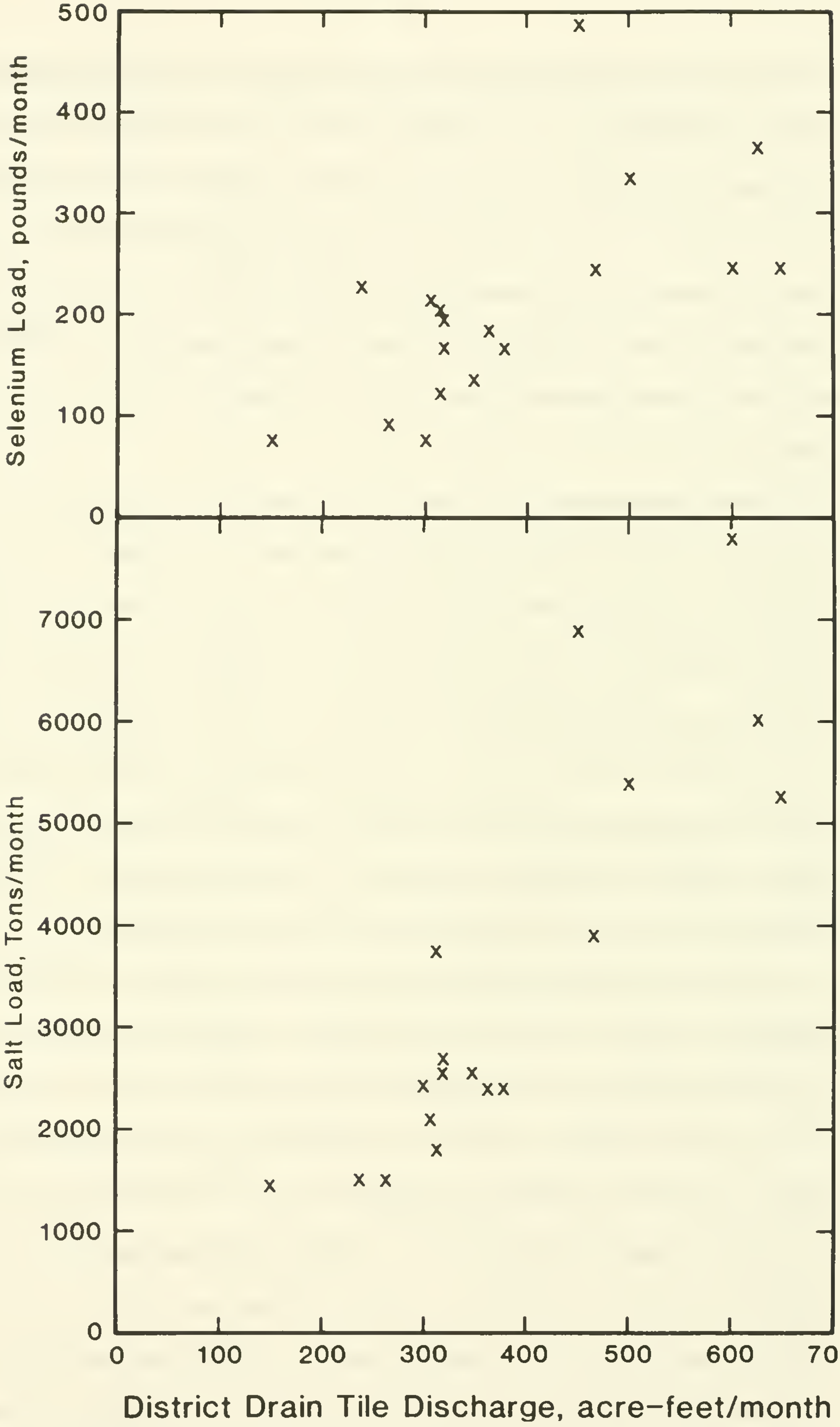

Figure 3.5 Selenium and salt load as a function of that fraction of the total discharge in the district drain from Broadview Water District attributed to subsurface drainage (25% of total flow) from November 1984 to April 1986.

The level of soil salinity is dependent upon the salinity level of the water and the amount of leaching of the crop root zone that takes place during normal irrigation practices. Applying more irrigation water than can be used by the crop (leaching) is is the only practical way to manage root zone salinity levels. For example, little, if any, intentional leaching is needed when the applied water salinity is less than 0.7 dS/m (460 ppm). The need for careful management increases; however, as water salinity increases, controlling soil salinity to acceptable levels becomes difficult.

Where management of shallow groundwater may include reduced leaching, use of blended water or direct use of drainage water for irrigation, maintaining soil salinity levels below those that affect certain crop yields may be impossible. An option available is to select crops that are tolerant to soil salinity levels expected and are economically viable to grow. The impact of salinity on the crop is a yield reduction caused by either an osmotic stress as a result of the total buildup of salts in the root zone or one or more of the specific ions in the salts causing direct damage to the crop. The second cause of yield loss is usually associated with the first, but the two do not have to be present together.

The relative salt tolerance of most agricultural crops is well known, although continued research is needed to expand our knowledge. The relative salt tolerances of crops common to the San Joaquin Valley are given in Table 3.2. The best method presently available to predict yield response is the Maas and Hoffman approach (1977). Their data indicate that decreases as a straight line function with increasing average soil salinity once a critical threshold salinity level at which yield first begins to decline is exceeded. There are deviations from the linear decrease; but the data show that these seem to occur at greater than 50% yield losses, which are commercially unacceptable anyway. These tolerance values were obtained under controlled laboratory conditions. However, recent field data show that the salt tolerance curves were independent of the irrigation technique used and the tolerance values could be applied to field conditions where soil salinity distribution is not uniform with soil depth, thus supporting the assumption of average soil salinity used in Table 3.2 (Hoffman, 1986).

The sensitivity of crops to yield loss due to salinity may depend upon the crop maturity and other environmental factors such as climate. The salinity tolerance presented in Table 3.2 applies primarily to the late seedling stage to maturity. There are not sufficient data to compare salt tolerance at different stages of growth, but it appears that tolerance during the germination and early seedling stage for some crops may be greatly different. For example, crops like barley, corn, rice, and wheat show sensitivity during the early seedling stage but are relatively tolerant during germination. These crops increase in tolerance as they mature and develop tolerance up to the critical threshold level, above which yields begin to decrease as shown in Table 3.2.

In the San Joaquin Valley, boron may be a significant limiting factor for crop production when using drainage water or improved irrigation efficiency on high boron soils. Like salinity, there is a range of tolerance to boron by crops. The tolerance curves for eight of the eleven crops studied to date are presented in Figure 3.6. Of the eleven crops studied, it has been shown that, although the threshold tolerance for boron levels varies widely among crops, yields do not decline rapidly as the boron levels increase in excess of the threshold value.

Trace elements are known to exist on the Westside including, but not limited to, arsenic, chromium, molybdenum, nickel, and selenium. Of most immediate concern is selenium and molybdenum. Few data are available on use of such water on soils already containing these elements. The Panoche Water District has been surveying mature crops of wheat and melons since 1985 and reports values less than one part per million (ppm), while crops grown in South Dakota commonly report levels in

TABLE 3.2

Salt Tolerance of Selected Crops as a Function of the Electrical Conductivity of the Soil Saturation Extract (c), where Relative Yield (Y_r) is in Percent = 100 - $S(c - c_t)$ and where $c \geq c_t$

Crop	Salt Tolerance Threshold[a] (c_t)	Percent Yield Decline[b] (S)	Qualitative Salt Tolerance Rating[c]
	dS/m[d]	%/(dS/m)	
Alfalfa	2.0	7.3	MS
Almond	1.5	19.0	S
Apricot	1.6	24.0	S
Barley	8.0	5.0	T
Bean	1.0	19.0	S
Beet, red	4.0	9.0	MT
Broccoli	2.8	9.2	MS
Cabbage	1.8	9.7	MS
Clover, red	1.5	12.0	MS
Corn	1.7	12.0	MS
Carrot	1.0	14.0	S
Cotton	7.7	5.2	T
Cowpea	1.3	14.0	MS
Cucumber	2.5	13.0	MS
Date Palm	4.0	3.6	T
Grape	1.5	9.6	MS
Grapefruit	1.8	16.0	S
Lettuce	1.3	13.0	MS
Onion	1.2	16.0	S
Orange	1.7	16.0	S
Peach	1.7	21.0	S
Peanut	3.2	29.0	MS
Pepper	1.5	14.0	MS
Plum	1.5	18.0	S
Potato	1.7	12.0	MS
Radish	1.2	13.0	MS
Sorghum	6.8	16.0	MT
Soybean	5.0	20.0	MT
Spinach	2.0	7.6	MS
Strawberry	1.0	33.0	S
Sugarbeet	7.0	5.9	T
Sugarcane	1.7	5.9	MS
Sweet Potato	1.5	11.0	MS
Tomato	2.5	9.9	MS
Wheat	6.0	7.1	MT

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[a] Salt tolerance threshold is the mean soil salinity at initial yield decline.

[b] Percent yield decline is the rate of yield reduction per unit increase in salinity beyond the threshold.

[c] Qualitative salt tolerance ratings are sensitive (S), moderately sensitive (MS), moderately tolerant (MT), and tolerant (T).

[d] dS/m = deciSiemens per meter = 1 millimho per cm, referenced to 25 C.

Source: Maas and Hoffman, 1977.

the 5 ppm range with no loss in yield or suitability of the product. Selenium uptake may be excluded by the high sulfate levels in some of the San Joaquin Valley soils, as researchers at University of California, Riverside, show its exclusion in the presence of high sulfate.

Molybdenum is known to accumulate in plant tissues with an especially high preference for legumes. Although molybdenum has been found in elevated concentrations in subsurface drainage water of the San Joaquin Valley (up to 1300 mg/L), it has never been shown to have a detrimental effect on crop yield. The concern is that bioaccumulation in forage reaches levels that prove selectively toxic to cattle and sheep and virtually nontoxic to other domestic animals, wildlife and humans. The method of toxicity appears to be the inhibition of copper storage. Normal to high sulfate levels appear to provide some protection as well as a copper to molybdenum ratio of 2:1 in forage. The uptake by plants is directly related to soil concentration. As the soils along the west side of the San Joaquin Valley are alkaline with high sulfate levels, there is some protection from molybdenum toxicity.

With the many limitations assigned to irrigating current commercial crops with subsurface drainage waters, some attention has been focused on new crops for agriculture. Known as Agroforestry, studies are presently being conducted on-farm in the San Joaquin Valley by the California Department of Food and Agriculture in conjunction with many state and federal agencies. The alternate crops are not only salt tolerant, but they also utilize large amounts of water from both irrigation as well as the shallow groundwater. Depending on the species selected, salts may even be accumulated in the plant tissue resulting in not only less, but also better quality water as drainage water.

Potential problems with Agroforestry are varied and unsettled. Current research in the San Joaquin Valley is less than three years old, so many pertinent questions have yet to be answered. Issues of concern include:

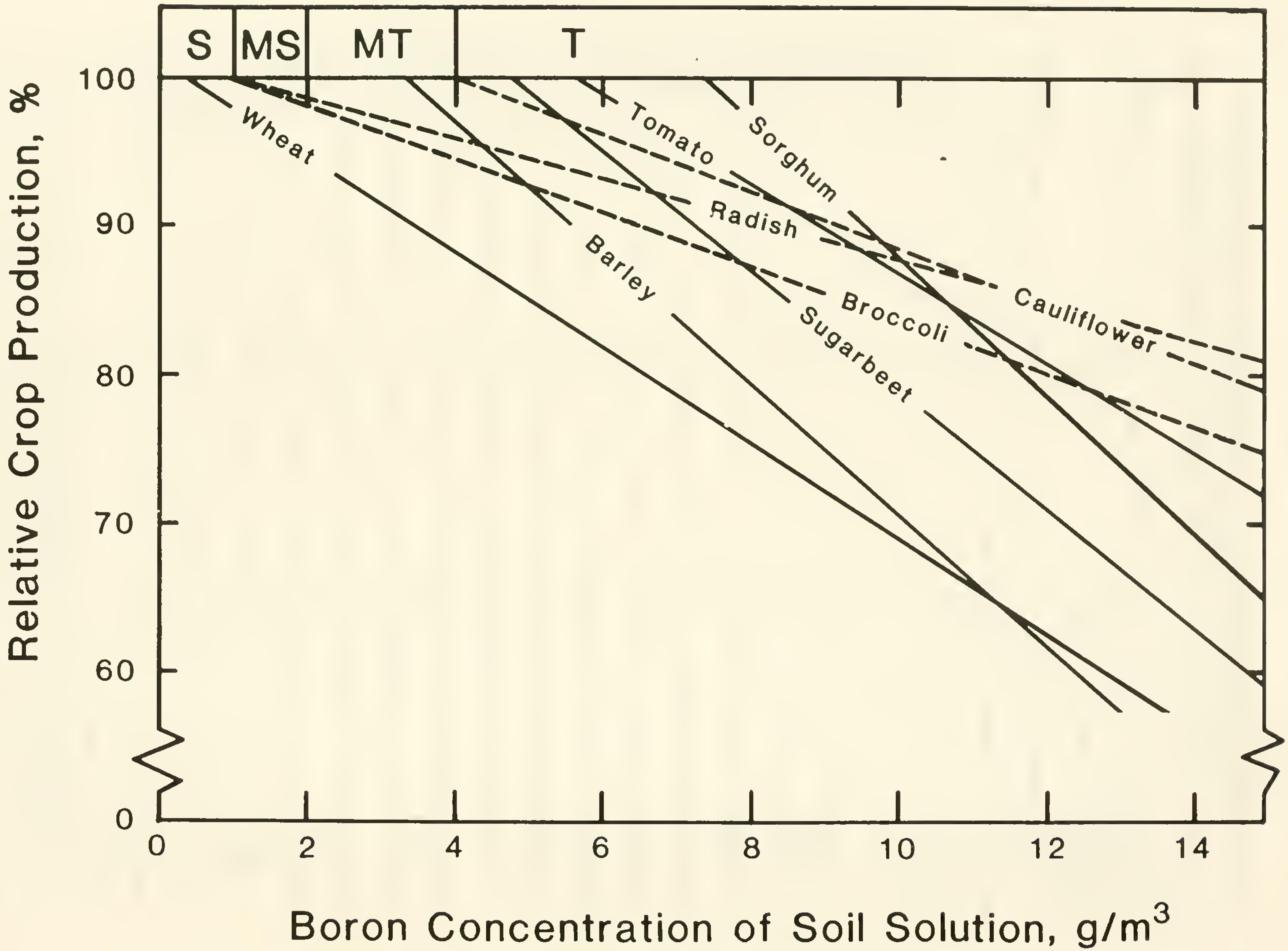

Figure 3.6 Tolerance curves of selected crops to boron. (See Table 3.2 for qualitative salt tolerance ratings.)

- salt buildup in the soils due to extensive evapotranspiration;
- accumulation of elements to hazardous levels and the possible effects on wildlife, harvesting, and disposal; and
- development of a viable market for the final crop.

Agroforestry may be a very valuable component in overall drainage reduction and should continue to be researched as such.

3.4.2 Recycling Drain Water

Minimizing leaching (drainage) always reduces the volume and salt load of the drainage water leaving the crop root zone and generally minimizes pollution of the receiving water (van Schilfgaarde et. al., 1974). For this reason, minimizing leaching and deep percolation should be the goal of irrigation management on the west side of the San Joaquin Valley. For those situations where the waters cannot be, or have not been, fully utilized in their first "passage" through the root zone, the drainage water should be intercepted before its discharge to water supplies of better quality and reused for irrigation (Rhoades, 1984). While concentrations of salts in drainage waters are higher than those of the corresponding irrigation water supply, they are often within acceptable limits for growing suitably salt-tolerant crops (Rhoades, 1977).

Blending

In considering reuse, it is important to recognize that the total volume of any natural water supply cannot be beneficially consumed for irrigation and crop production; the greater its salinity, the less it may be consumed. The practice of blending or diluting excessively saline waters with good quality water supplies to meet discharge standards and to increase water supplies is often wasteful and sometimes harmful to the subsequent consumers of the blended water. Therefore, one should consider the consequences of blending waters, with respect to how it affects the volume of usable water, before any decision is made to do so.

Plants must have access to water of a quality that permits consumption without the concentration of salts (individually or totally) becoming excessive for adequate growth in the process. In the process of transpiration, plants separate nearly pure water from the soil solution and they concentrate the salts in the remaining unused soil water. Thus, not all of the water in a supply can be consumed by a plant, if it contains salt. A plant will not grow properly when the salt concentration in the water bathing its roots exceeds some limit specific to it under the given conditions of climate and management (Bernstein, 1975).

The average level of soil salinity[1] (expressed as the electrical conductivity of the saturation-paste extract, EC_e) within the crop root zone resulting from the long-term irrigation with a water of EC_{iw} is predicted from

$$EC_e = F_c \cdot EC_{iw}$$

where EC_{iw} is the electrical conductivity of the irrigation water in dS/m and F_c is the relating concentration factor appropriate for L. The relationship between F_c and L is the same as that between F_c and Lr, which is depicted in Figure 3.7 (Rhoades, 1984). Thus, if the EC of the irrigation water is 0.5 dS/m and the leaching fraction is 0.15, then F_c is 1.51 and the average level of salinity within the active root zone is predicted to be 0.75 d/S/m (0.5 x 1.51).

This successive use of low- and high-salinity waters will prevent the soil from becoming excessively saline while permitting, over the long period, substitution of a saline water for the conventional water for a substantial fraction (up to

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[1] The average concentration of the individual toxicant would be calculated by equation 1 for this case. For example, for boron it would be B_e.

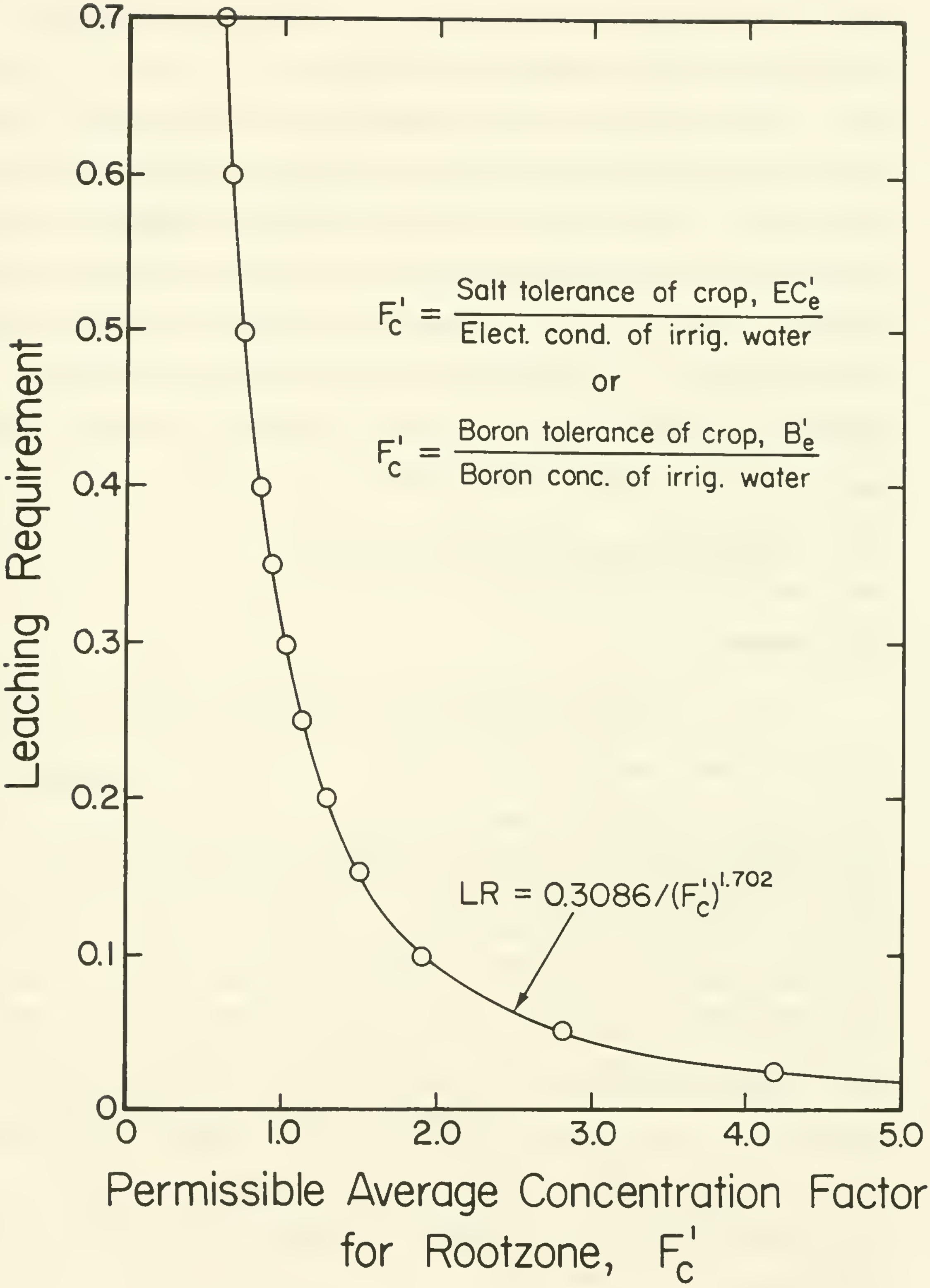
Leaching Requirement
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1.0
2.0
3.0
4.0
5.0
Permissible Average Concentration Factor for Rootzone, F_c'
$F_c' = \frac{\text{Salt tolerance of crop, } EC_e'}{\text{Elect. cond. of irrig. water}}$
or
$F_c' = \frac{\text{Boron tolerance of crop, } B_e'}{\text{Boron conc. of irrig. water}}$
$LR = 0.3086/(F_c')^{1.702}$

Figure 3.7

about 50% depending on the crop rotation) of the irrigation water needs of the area and the growth of salt-sensitive in the same fields.

Although continuous recycling of drainage water, in the sense of a closed loop, is not possible, reuse efforts should be designed so that the drainage waters intercepted are redistributed to a dedicated "reuse-area" within the project, or sequentially from areas where crops of lesser to greater salt-tolerance are grown (often this occurs naturally from upslope to downslope lying lands). The ultimate minimized volume of drainage must eventually be desalted or else disposed. This ultimate disposal should not be accomplished by discharging the drainage water into good-quality water supplies, unless no other means is practical.

3.5 RECOMMENDATIONS AND CONCLUSIONS

3.5.1 Research

The fact that many questions remain about drainage implies that research is required. Although research is not normally a quick process, it is urgently needed on load-flow relationships for salts, boron, selenium, and molybdenum, and alternative drain water and crop management strategies. Whereas the load-flow relationships for salinity and boron are relatively well-known, those for selenium and molybdenum are poorly understood. Load-flow relationships for minor elements require a concentrated research endeavor. Sources of salts and minor elements and their pathways are perhaps the least understood components of the drainage problem. Because of the complex interactions between sources and pathways, a major research thrust is required. Solutions to these questions are already being sought by the U. S. Geological Survey and the University of California but will, no doubt, require several years.

Management strategies under consideration include recycling drain water, alternate crops, and temporary plugging of the drainage systems. Prospects for successfully recycling drain water for irrigation have been demonstrated in several locations in California including those near Lost Hills, Brawley, Corcoran, and Mendota; additional large-scale studies would certainly be beneficial. Some of the additional research requirements could probably be accomplished in cooperation with growers currently recycling drain water near Mendota. Alternate crops suitable to the west side are currently under study on a small scale. If alternate crops with potential are identified, additional tests will be needed. Strategies for managing the shallow water table by periodically plugging the drainage system require immediate funding. Managing shallow water tables rather than always draining to a specified depth is a new research concept and, if successful, would be extremely beneficial. The drainage volume produced by a tiled field would be reduced by the amount of water used by the crop from the shallow groundwater.

3.5.2 Monitoring

Resolution of the drainage problem requires a more complete database than is currently available. For example, a number of irrigation districts are measuring drain flow volume and the concentration of constituents present, but mixtures of surface and drainage waters compound the data. A complete and standardized method of measuring drainage water constituents and volume is needed and development of this methodology should be initiated immediately.

Monitoring water table elevations is equally important. Although some areas have an extensive monitoring program, others do not. It is crucial that we know the water table elevation of the shallow water tables outside, as well as within, areas presently tile drained. Whether the water table is rising or falling is paramount to determining the magnitude of the drainage problem in the future.

In concert with efforts to reduce drainage comes the threat of increased soil salinity. New and rapid techniques of monitoring soil salinity are available, and research has shown these techniques to be accurate in large-scale field studies. As irrigation efficiency increases, shallow saline water tables become more prevalent, or, as drainage water is recycled for irrigation, the status of soil salinity must be monitored more frequently to assure that excess salinity levels do not develop. A soil salinity monitoring program should be initiated immediately; also characterizing salinity effects using aerial photography should be investigated.

SECTION 4

IRRIGATION PRACTICES AND EMERGING TECHNOLOGIES

4.1 INTRODUCTION

The objective of this task group is to present a range of existing and emerging irrigation technologies which show promise for reducing subsurface drainage via source control in the San Joaquin Valley (SJV). Surface, sprinkle, and trickle technologies are described and, based on both physical and economic considerations, recommendations are made in the context of short-, intermediate-, and long-term solutions to the current drainage problem.

4.2 IRRIGATION PERFORMANCE MEASURES

Water applied by irrigation may go into the air as evaporation, spray loss, or transpiration; it may run off the surface of the field; and/or infiltrate the soil and be stored in the root zone or exit below as deep percolation. Excess deep percolation contributes to high water tables in the impacted area and thus will be a primary focus in later discussions.

In comparing irrigation systems, it is important to establish criteria which can be used to judge performance. Efficiency and uniformity are one set of commonly used measures.

Irrigation Efficiency (IE) is:

$$\mathrm{IE} = \frac{\text{average depth of applied water beneficially used}}{\text{average depth of water applied}} \times 100$$

Crop transpiration is an important beneficial use. By definition, water used for salt leaching, frost protection, crop cooling, and pesticide or fertilizer application may also be considered as beneficial uses. Nonbeneficial uses include weed transpiration; deep percolation in excess of leaching requirement (especially important in impacted areas); runoff, if not collected and reused; evaporation from wet soil surfaces; canal and pipe seepage; and spray losses. Under normal irrigation practices, spray and evaporation losses are rather small; but, under high winds, they may be significant, particularly with sprinkle irrigation.

Application Efficiency (AE) is:

$$AE = \frac{\text{average depth of water stored in root zone}}{\text{average depth of water applied}} \times 100$$

Irrigation water stored in the root zone is potentially accessible for evapotranspiration. Because AE does not include spray losses, leaching, frost protection, crop cooling, and pesticide or fertilizer application as beneficial uses, its value is usually less than that of IE.

The AE and IE give no indication of adequacy or uniformity of the irrigation; and, with exaggerated underirrigation, they can equal 100 percent.

Distribution Uniformity (DU) is:

$$DU = \frac{\text{average low quarter depth of water infiltrated}}{\text{average depth of water infiltrated}} \times 100$$

Average low quarter depth infiltrated is the average of the lowest quarter of the measured or estimated values, where each value represents an equal area. The DU is a useful indicator of distribution problems. A low DU indicates that excessive deep percolation losses will occur if adequate irrigation is supplied to all areas.

Another measure of uniformity is Christiansen's uniformity (CU):

$$CU = \frac{\text{average depth infiltrated in the low half}}{\text{average depth of water infiltrated}} \times 100$$

The relationship between CU and DU can be approximated by:

$$DU = 100 - 1.59(100 - CU)$$

An illustration of the destination of applied water is presented in Figure 4.1. Applied water is evaporated, runs off (which may or may not result in loss), is stored in the root zone, and is lost to deep percolation due to overirrigation

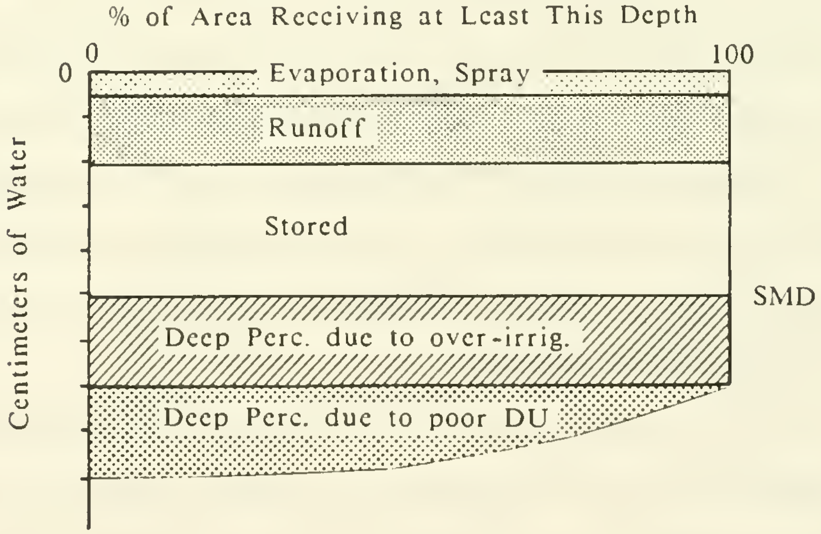
% of Area Receiving at Least This Depth
0
100
0
Evaporation, Spray
Runoff
Stored
SMD
Deep Perc. due to over-irrig.
Deep Perc. due to poor DU
Centimeters of Water

Figure 4.1 Destination of applied water for a case of overirrigation. Deep percolation is due to both poor timing and non-uniformity.

(irrigation of too long duration and applied water exceeding soil moisture deficit) or due to poor uniformity.

Overirrigation is a problem in the drainage-impacted areas, especially when surface irrigation methods are used. Because infiltration rates are high early in the season, when the surface is flooded, more water is infiltrated than can be stored and excess deep percolation occurs. In addition, because intake is high during this period, water advances across the field slowly despite high inflow rates and excess water infiltrates at the upper edge of the field. Uniformity is low and deep percolation is high. To reduce losses from overirrigation and nonuniformity, growers can force the water across the field more quickly by increasing inflow rates. However, doing so may increase runoff to unacceptable levels, unless the runoff water is reused.

4.3 IRRIGATION SYSTEM PERFORMANCE AND ECONOMICS

Water costs such as applied water, system hardware, and management have been charged against crop revenues. Systems and management strategies were chosen to maximize profits. Especially where irrigation return flows (surface runoff and deep percolation) cause adverse environmental impacts, however, the profit function should be expanded to include terms which reflect the cost of disposing of or recirculating the water. The objective in such an analysis is to select and manage technologies to achieve a desired environmental quality, while at the same time realizing profits acceptable to growers.

To obtain an optimal solution, system hardware, labor, drainage and runoff water, irrigation water, and management costs should be related to uniformity and average water application. Yield benefit should also be related to uniformity and average water application. The relationship between subsurface drainage and uniformity and average water application is used next to illustrate the importance of the water application system in source control.

Depth of water infiltrated and the portion of field area receiving that depth for an assumed sprinkling system are shown in Figures 4.2. Figure 4.2a and 4.2b show the distribution of water for a sprinkler system with a DU equal to 70 percent. Figure 4.2c and 4.2d show the cumulative distribution for a DU of 40 percent. Although these data are from sprinkler system evaluations, the relationships are the same for other types of irrigation systems with similar DUs.

In Figure 4.2a, the dashed line shows that 80 percent of the irrigated area received at least three inches of water, the required irrigation depth for this example. Average depth applied is 3.8 inches, and area deficit or under-irrigated is 20 percent. Amount of subsurface drainage, represented by the cross-hatched area above the dashed line and below the solid line, is 21 percent of applied water. If average water application is reduced to 2.8 inches (Figure 4.2b) in an effort to reduce deep percolation, 60 percent of the irrigated area will receive less than the desired three inches, and is, thus, underirrigated. On the average, the under-irrigated area receives a shallower depth of application. Although subsurface drainage is reduced to six percent of average depth applied, yield will decline since a greater percentage of area is underirrigated. Decline in benefits, due to yield reduction and potentially greater management costs, should be weighed against the irrigation water and drainage water disposal cost reductions. This approach may be contrary to the concept that excess water application is "cheap insurance" to guarantee high yields.

If the system applies water less uniformly (DU equal to 40, Figure 4.2c), average depth applied must increase from 3.8 to 5 inches to apply at least 3 inches to 80 percent of the irrigated area. Subsurface drainage doubles from 21 to 42 percent of the average depth applied. The system is operating as efficiently as

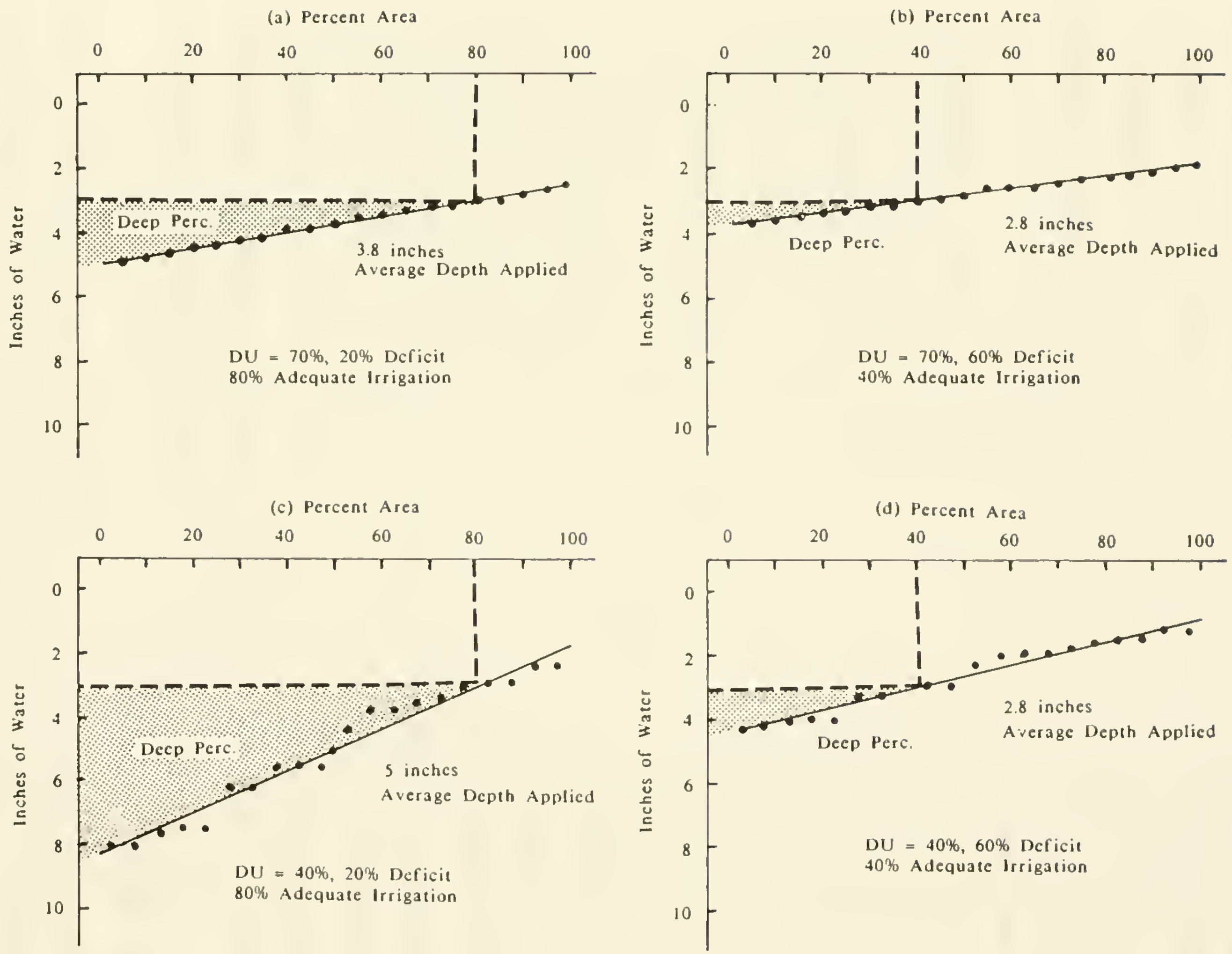

Figure 4.2 Distribution of water infiltrated into an irrigated area related to uniformity and average infiltration depth.

possible under these conditions. Again, subsurface drainage can be reduced to 11 percent of average applied water by deficit-irrigating nearly 60 percent of the field (Figure 4.2d). However, yield declines, and profits may decrease if the decline in yield is greater than the decrease in water and drainage costs.

If the system with a DU of 40 percent is managed differently, or is replaced with a more uniform system with a DU of 70 percent, yields should increase and drainage and water costs should decrease, resulting in increased profits. This assumes that the management and hardware costs of making the change to higher uniformity are less than the increase in profit calculated without their consideration.

Overirrigation is illustrated in Figure 4.3. If the least watered area receives 4.5 inches in excess of the 3-inch desired depth, average depth applied is 12 inches. The amount of subsurface drainage is 75 percent of this depth, or 8 inches for DU equal to 70 percent. For a DU of 40 percent (not shown), subsurface drainage is 9 inches, or 60 percent of the average depth applied (15 inches). Substantial reductions in drainage and water costs will occur in both cases simply by decreasing the average depth applied, without deficit irrigating. In addition, yield may also increase if it was previously depressed by excess irrigation.

In summary, if over-irrigation from the first few irrigations, coupled with winter rainfall is the major contributor to the drainage problem in impacted areas, then substantial drainage reduction may occur by decreasing average depth of water applied. This could be achieved by modifying existing management practices at minimum cost. Profits should thus increase. If, however, the subsurface drainage comes from irrigation systems operated as efficiently as possible, significant drainage reduction will result only if substantial deficit irrigation occurs, or if existing systems are replaced with ones capable of attaining very high uniformities at potentially high cost. Profits may still increase. If a system is operated as

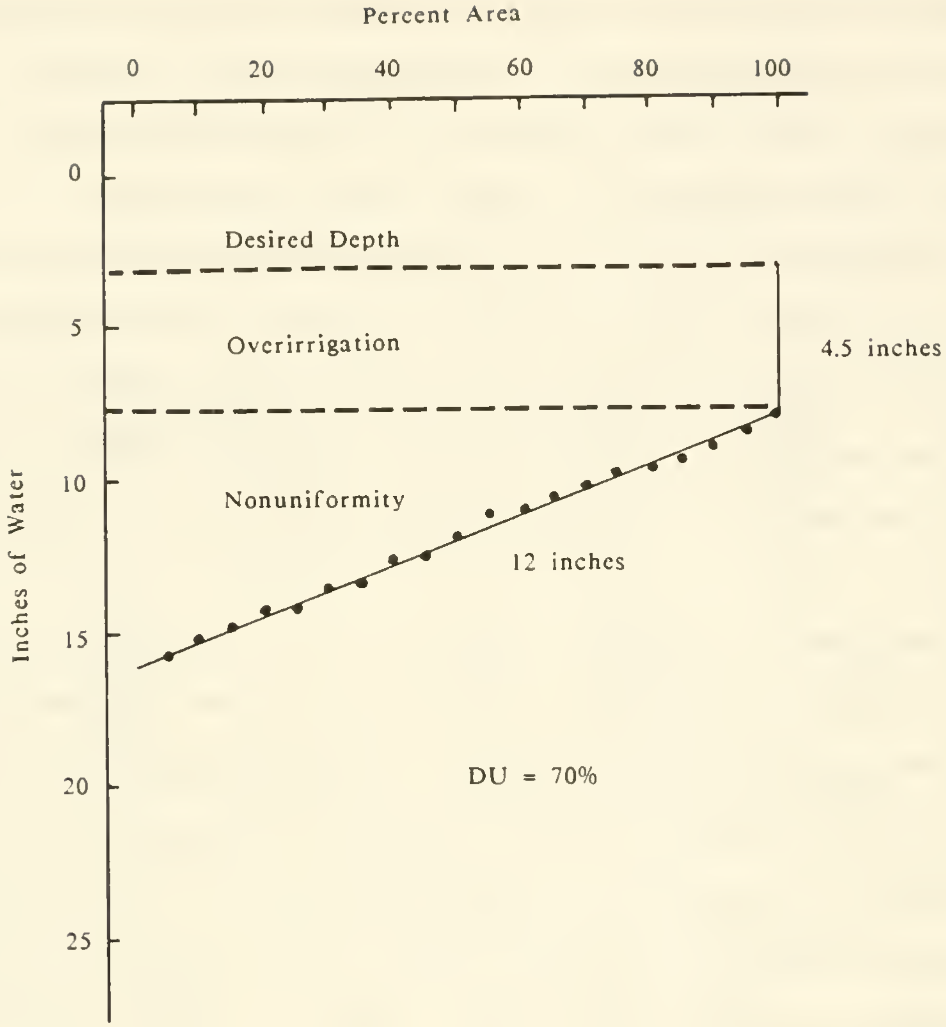

Figure 4.3 **Distribution of water infiltrated for an overirrigation.**

efficiently as possible under existing conditions, drainage reductions will occur only through deficit irrigation. The higher the system uniformity, the smaller the deficit amount throughout the field, and thus the smaller the resulting yield reduction. Again, the increase or decrease in profits will be site specific.

4.3.1 Seepage Losses

The magnitude of seepage losses in canals, ditches, and tailwater sumps is not known for the drainage area. Seepage losses are difficult to measure because flow measurement devices used to study seepage losses are only accurate within 3 to 10 percent in field studies, and seepage losses in a section of canal being studied may only be 2 to 3 percent for that length.

Seepage losses change during the season, with higher losses occurring during the beginning of the irrigation season than at the end. The major types of losses are:

A. irrigation district canal losses:
   1. during initial filling up of dry canal,
   2. during the irrigation season;

B. on-farm ditch;

C. tailwater ponds.

Tailwater seepage losses are minor or negligible as compared to deep percolation losses from nonuniform irrigation. Proper use of tailwater recovery systems is often essential in obtaining high irrigation uniformities with surface irrigation, so it would be a mistake to recommend the elimination of tailwater ponds based solely on their seepage losses.

Similarly, losses from on-farm ditches examined independently may seem high. However, the net effect of adding extra ditches across a field to shorten furrow lengths will be positive because short furrows can be managed to result in higher distribution of water application. Nevertheless, there may be additional significant savings of water if ditches are converted to gated pipe.

The magnitude of the various seepage losses will depend on the flow rates, soil types, time of year, and amount of time water is in ditches or canals. As a very rough, preliminary estimate, seepage losses in the area may fall into the following ranges:

Canal seepage	5-15%	(Applies only to areas with canals for water distribution)
On-farm ditches	3-15%	of field applied water
Tailwater sumps	1- 3%	of field applied water

4.4 IRRIGATION SYSTEM TECHNOLOGIES

Irrigation consists of introducing water into the part of the soil profile which serves as the root zone where it is subsequently used by the crop. A well-controlled irrigation system is one which distributes water to maximize profits. Because economic considerations are necessarily specific to each location and set of circumstances, the optimal irrigation system at one site may not be as effective at another site. Existing and emerging surface, sprinkle and trickle irrigation systems, relevant to the impacted area, are presented in the following sections. Primary consideration is given to the expected uniformity and depth of water application, and the relative costs of achieving that uniformity in the context of the discussion of "Irrigation System Performance and Economics."

4.4.1 Surface Irrigation - Existing Technologies

Surface irrigation is the process of applying water at a point or at the edge of a field, and allowing gravity and hydrostatic pressure forces to spread the flow across and down the field. Using this method, soil serves the dual role of water conveyance and infiltration; surface irrigation is less capital intensive than systems that deliver water to the point of infiltration. Application uniformity may be low using surface irrigation because it depends on the time required for water to advance across the field (advance time), and on the variability of the soil's infiltration rate. The following is a summary of causes of nonuniformity:

- low inflow rates and excessive field lengths, which result in lengthened time to spread water down the field;
- intraseasonal changes in infiltration properties;
- spatial variability of infiltration properties;
- variability in infiltration between furrows caused by wheel traffic and other cultural practices;
- variability in inflow rates during the irrigation and between furrows and borders;
- variability in irrigation time (duration) between sets and during the season.

Furrow/Border. Because of the advance time, differences in time for infiltration (intake opportunity time) exist between the upper and the lower end of the field. This results in nonuniformities in the depth of water infiltrated. Uniformity can be improved by decreasing the difference in intake opportunity time; intake opportunity time can be reduced through decreasing advance time by:

1. increasing the furrow inflow rate during the advance,
2. reducing the length of run,
3. establishing a uniform grade in the field.

To realize the benefit of measures 1 through 3, the following are recommended:

4. recirculate or reuse surface runoff;
5. cutback flow to reduce runoff.

(In most cases, the modifications suggested above cost less than $50/acre.)

While differences in infiltration opportunity time can be reduced, the maximum uniformity of a surface irrigation system is limited by the spatial variability of soil infiltration rates. Studies of spatial variability of infiltration revealed a water application uniformity of 70 percent, if intake opportunity was uniform. This DU may represent an upper limit since these fields were described as having a relatively uniform soil texture. If no deficit irrigation and differences in infiltration times occurred, about 20 percent of the applied water would be subsurface drainage.

Although knowledge of management strategies to reduce spatial variability are limited, intake can be reduced by:

6. packing furrows artificially, i.e., torpedos;
7. wheel trafficking a greater proportion of furrows.

Water supply control can help reduce variability in water application. Strategies include:

8. minimizing set time differences;
9. maintaining constant flow rate during set;
10. maintaining consistency between furrow flow rates.

The use of computer models has and will play an important role in managing and modifying surface irrigation systems. Ability to predict water distribution prior to an irrigation is a strategic tool in system optimization for environmental protection and profit maximization in the presence or absence of a water table.

4.4.2 Surface Irrigation - Emerging Technologies

Surge Irrigation. Surge flow irrigation is "the intermittent application of water to furrows or borders creating a series of on and off periods of constant or variable time spans." Usually water is alternated until the irrigation is completed. Switching is accomplished with a surge valve and an automatic controller. In a typical installation, water is delivered to a surge valve and controller located between two irrigation sets. Gated pipe is used to distribute the irrigation water to each of the two sets from opposite sides of the surge valve. Surge flow greatly reduces the intake at the upper end of the field because the opportunity time and infiltration rate are both much less than they would be under conventional flow methods. Thus, a shallower depth can be applied more uniformly.

Reasons for the surge effect (reduced water volume for advance) are not fully understood, but several have been suggested. Surging creates a wetting time and a drying (recession) time for each surge; this allows water to soak in a dissolve soil clods, thereby allowing the soil to settle with the water to form a slick, consolidated, sealed surface. This reduces the intake rate and produces a smoother and hydraulically efficient surface for the next surge.

Although soil specific, several evaluations of surge irrigation on the west side of the SJV have shown that about 50 percent less water is required for water advance across the field as compared to the continuous inflow method. This difference indicates a potential for surge irrigation to reduce subsurface drainage during the first few irrigations of the season, when relatively high infiltration rates exist and water table rise is common. However, if the infiltration rate is reduced, water penetration may be less than evapotranspiration; and the crop may be stressed. Surge system costs may range from $200-$400/acre.

Cablegation. Cablegation is an automated gated-pipe system. The gates or outlets are near the top side, and are left open. The pipe is laid on a precise grade, and a plug moves slowly through the pipe, causing water to flow in sequence to furrows or border strips in the field. A single pipe is used both to transmit the water along the edge of the field and to distribute equal amounts to furrows or border strips. The cost of a cablegation system is in the range of $200-$250/acre. Many gated-pipe systems can be retrofitted to become cablegation systems for the cost of the controller and associated hardware and installation of the system to grade.

Flow into the furrow is maximized at the beginning of the irrigation set and decreases with time as the set continues. This tends to minimize both deep percolation losses and tailwater runoff in furrow-irrigated fields. Irrigation uniformities of 80 have been suggested with the use of cablegation on the heavy soils of the west side of the SJV. Work is continuing on feedback control of the plug speed to control tailwater runoff and on pumpback of tailwater to the system. Both options could be very beneficial to irrigation in the SJV.

Cablegation is particularly suited to fields with adequate slope (greater than 0.0025 m/m) across the field. However, this condition does not exist in many areas on the west side of the SJV, and modifications to the land surface to achieve this grade are not practical. Although in Idaho the technology has been successfully demonstrated to improve runoff water quality, uncertainty in applying this system to California conditions preclude its listing at this time as a recommended drainage reduction technology. Furthermore, the problems inherent in surface irrigation are also present in cablegation (i.e., soil variability, compaction in wheel rows, variability of infiltration rate, and differences in intake opportunity time).

Level Basin Irrigation. Level basin irrigation has successfully reduced subsurface drainage flows in the Welton-Mohawk Valley of Arizona. This irrigation method applies water at a high inflow rate to dead-level basins. No surface runoff occurs. Irrigation efficiencies of as high as 90 percent have been reported for these systems. A study on the west side of the SJV showed subsurface drainage reduction at minimum labor and energy costs using this method. To operate effectively, a level basin system requires a field inflow rate of 15 to 20 cfs, lengths of run no longer than 1/8 mile, and very precise land leveling. Unfortunately, many water distribution systems along the west side of the SJV lack the needed flow rate. Another constraint on the use of level basin irrigation is the natural slope of the west side, which would require considerable cutting and filling, even for benched fields.

Controlled Volume Irrigation on Sloping Fields. With surface irrigation, the rate at which water infiltrates the soil changes during and between irrigations. If a surface irrigation system is managed for a high uniformity (which requires high flow rates and tailwater) and no underirrigation, it is very difficult to know in advance the proper irrigation set duration.

With controlled volume irrigation, an irrigator applies a flow rate of water to a group of furrows or a single border strip (an "irrigation set") for a specific, predetermined amount of time, without concern about infiltration or tailwater. At the end of that time period, the water supply is switched to an entirely different portion of the field with an independent tailwater system.

All of the water applied to the first set is picked up by the tailwater system for that part of the field and returned to that first set until it all infiltrates, so the volume applied (known in advance) equals the volume infiltrated. A large field must be broken in 2-3 "subunits," each with an independent delivery line and tailwater system. The water supply is rotated between subunits so that there is time for all tailwater from any one set to be returned and infiltrated into the same set area. The concept allows accurate and simple control of irrigation scheduling information. The effect is to make a sloping field manageable in the same manner as level basins.

4.4.3 Sprinkle Irrigation - Existing Technologies

Sprinkle irrigation is the application of water in the form of a spray created by expelling water under pressure from an orifice or nozzle. It can be considered as man-made rain in that its frequency, intensity, and duration can be controlled. In contrast to surface irrigation systems, sprinkle systems are designed to deliver water to the soil surface without depending on the soil surface as a conveyance medium. To prevent ponding and surface flow, the sprinkling rate is designed to be less than the infiltration rate of the soil.

Under favorable conditions, high application efficiency of a sprinkle system can be achieved with a properly designed and operated system. Excess application, characteristic of surface systems during early irrigations when infiltration is high, is reduced under sprinkling; and the associated water table buildup can be slowed or avoided. Further, sprinkle system performance may not depend on the water table to redistribute applied water and to serve as a reservoir for consumptive use between irrigations, as is discussed later in conjunction with water table management.

Causes of nonuniformity include:

- improper average operating pressure;
- variability in pressure along the mainlines and laterals;
- improper nozzle diameter and type along the lateral;
- improper sprinkler spacing between the lateral for all systems, and between sets along the mainline for stationary systems;
- excessive application rates which cause runoff;
- wind;
- start/stop motion of continuous move systems.

High initial capital costs, in contrast to surface systems, must be depreciated over the life of the sprinkling system. Careful design and analysis are recommended to achieve the potentially high performance of sprinkle irrigation at minimum cost.

The following are examples from the west side of the results of poorly managed irrigation systems. At one site, on which sugar beets were being grown, a hand-move sprinkler system was used on half-mile runs with 3-inch aluminum pipe. The pipe was borrowed from a neighbor and had low-pressure nozzles. This system was evaluated and was found to have a DU of 35 percent. The sprinkler nozzles were changed to the standard 7/64-inch size, and the system was then found to have a much higher DU of 66 percent. On another site, sprinkle irrigation was used on tomatoes for the first irrigation after emergence. This irrigation was done not for moisture replenishment but rather for soil conditioning. The root zone of the tomatoes was found to have a moisture depletion of .75 inches. Water was applied in a 12-hour set, resulting in 2.86 inches applied, with an average infiltration of 2.43 inches and deep percolation of 1.68 inches. These sprinklers were used under windy conditions, and the DU was evaluated at 50 percent, resulting in an IE of 26 percent. Had the recommended set of 6 hours been used, the system would have achieved a much higher efficiency rating.

Hand Move/Side Roll. A maximum practical DU, measured for hand-move sprinkler systems used along the west side of SJV, is about 70 percent, given low wind. For systems operating below design pressure and in high wind, DUs of 40 percent have been measured. Thus, referring to Figure 4.2c and 4.2d, the periodic-move sprinkler system will at best produce about 20 percent of the applied water as subsurface drainage unless deficit irrigation occurs.

In addition to correcting the causes on nonuniformity previously listed, uniformity under hand-move systems can be improved by:

- using offset lateral sets;
- installing flow control nozzles;
- shortening risers to reduce wind distortion.

Linear Move. Sprinkler machines classified as continuous-move, such as linear-move systems, are assumed to have high uniformity as compared to periodic-move systems, particularly under relatively high wind conditions. Linear-move machines with spray nozzles on drop tubes have had measured uniformities of between 60 and 70 percent. Causes of nonuniformity in these systems were inadequate overlap of the wetted pattern of the spray nozzles and the start-stop sequence of the machines (although these machines are called continuous-move, movement occurs in a series of starts and stops controlled by a guide tower). Uniformity may be improved by:

- adjusting spray boom angle;
- converting from drop tubes to booms;
- using flow control devices;
- renozzling.

The potential of these machines for drainage reduction is most likely greater than for hand-move systems. However, under windy conditions and with improper maintenance, it is difficult to realize the potential uniformity. The high application rates of these systems, however, may cause substantial surface runoff for the west side SJV soils. Cracks, which form upon drying, however, act as mini-reservoirs and help control runoff. Capital investment of continuous move systems is high relative to surface or hand-move systems, at $800/acre.

4.4.4 Sprinkle Irrigation - Emerging Technologies

Modified Continuous-Move. In areas where the intake rate is too low for conventional continuous move systems, wind is high, foliar salt burn is a hazard, and energy costs are high, linear-move machines have been converted to drop tubes supplying water to individual furrows rather than using sprayers or sprinklers. Furrow dikes are used every 3-5 feet to prevent surface runoff on sloping ground.

DU of 90 percent has been measured for this type of system. However, irregular start-stop movement may decrease this potentially high DU. Furrow dike spacing also plays a role in determining uniformity. In addition, the dikes may require a change in the harvest techniques and equipment currently used in the SJV. Again, the issue of high capital costs plays an important role in attempting to justify this technology for drainage reduction.

4.4.5 Trickle Irrigation - Existing Technologies

Trickle irrigation is the slow, localized application of water on or below the soil surface. Water is applied at a point or a grid of points, or is sprayed over small areas by miniature sprinklers. Water flows into the soil from the point of introduction and is distributed to the roots. As the supply of water is very frequent, or even continuous, the soil plays a less important role as a moisture storage reservoir in trickle irrigation than in surface and sprinkle irrigation. With trickle irrigation, attention shifts from soil moisture storage to daily crop water use.

Causes of nonuniformity include:

- improper average operating pressure;
- variability in pressure within the system;
- emitter variability;
- improper emitter spacing;

- emitter plugging;
- excessive application rates which cause runoff.

Surface Tubing or Tape. Trickle irrigation can save water by reducing or eliminating wetting of surface area, thus decreasing the evaporation component of consumptive use. The magnitude of this effect is presumably related to the degree of plant cover; but, in any case, the amount of water that can be saved depends on the quality of the system's design, management, and maintenance.

Theoretically, trickle irrigation systems are capable of high uniformities and efficiencies, but evaluations of on-farm systems have found lower uniformities. Of 57 drip irrigation systems evaluated in the SJV, 10 had DUs greater than 90, 35 had DUs between 70 and 90, and 12 had uniformities of less than 70 percent. Causes for the lower uniformities were water quality and poor filtration with subsequent plugging and excessive variability between emitters.

Uniformity can be improved by:

- improving water filtration;
- reducing emitter variability
- decreasing pressure variation and operating at appropriate average pressure.

Capital investment for trickle irrigation systems is high because large quantities of pipes and emitters are required to deliver water to specific locations in the field via a closed conduit (rather than via the air or the soil surface, as in sprinkle and surface irrigation). In addition, because the emitter flow passages are narrow, expensive filtration equipment is necessary to clean the water. Labor saving automation adds to the cost. In general, trickle systems are more expensive ($1,200/acre) than surface or sprinkle systems. But, as mentioned, potential uniformity is very high.

4.4.6 Trickle Irrigation - Emerging Technologies

Subsurface Tubing or Tape. By burying tubing below the soil surface, evaporation losses can be eliminated. Trafficability is enhanced, traffic-related soil compaction is reduced, weed control is enhanced, and soil surface crusting is avoided.

As with surface trickle systems, there are difficulties in achieving potential high uniformity if good filtration and water management techniques are not followed. A major constraint is that costs are even greater than for surface trickle systems. In addition to the added cost of burying the tubing, there are problems with using this method for crop germination. However, germination has been accomplished using this method in both Arizona and California.

4.4.7 Summary of Potential Uniformities and Efficiencies

Tables 4.1 and 4.2 summarize potential system uniformities and efficiencies. Ranges of values were given purposely to account for variations in local conditions. As stated in Section 4.3, the decision on technology and its management must come from incorporating economic considerations into the physical and biological system.

4.5 IRRIGATION MANAGEMENT TECHNOLOGIES

4.5.1 Irrigation Scheduling

Irrigation scheduling will reduce total volume of subsurface drainage if better timing of irrigations reduces overirrigations and if better estimation of soil water depletion between irrigations decreases the average depth of applied water (Figure 4.3).

In areas without shallow groundwater, soil water depletion can be estimated by assuming that the required irrigation depth (soil water depletion) equals the total

TABLE 4.1

SUMMARY OF SYSTEM UNIFORMITIES

Potential Field Uniformities	Distribution Uniformities (percent)
Permanent undertree sprinkler	90 - 94
Linear-move sprinkler	75 - 90*
Sloping furrow	70 - 80**
Orchard drip (2-3 years)	85 - 90
Border strip	70 - 85
Row crop drip	80 - 90
Hand-move sprinkler	70 - 80

* Higher DU for booms.

** Assumes soil moisture deficit compatible with efficient operation, does not include soil variability.

TABLE 4.2

SUMMARY OF SYSTEM EFFICIENCIES

Potential Efficiencies (adequate irrigation)	Irrigation Efficiency (percent)
Permanent undertree sprinkler	85 - 90
Linear-move sprinkler	75 - 85
Sloping furrow	75 - 85
Orchard drip (2-3 years)	80 - 85
Border strip	65 - 80
Row crop drip	75 - 85
Hand-move sprinkler	65 - 75
Furrows and hand-move efficiencies for preirrigation	35 - 60
Later efficiencies	approx. 100

evapotranspiration between irrigations. In areas with shallow saline groundwater, substantial amounts of saline groundwater are used by the crop, and thus soil moisture depletion between irrigations will be less than the calculated evapotranspiration. At a site on the west side of the SJV, the average soil water depletion between irrigations was about 70 percent of the evapotranspiration. This depletion must be estimated either directly using neutron probes, tensiometers, or other moisture measuring devices, or by adjusting the expected depletion for crop use.

4.5.2 Drain Water Use

Many studies have shown successful use of saline drainage water for crop production. Low-salinity water was applied for crop establishment, after which saline water was used. Crops used in these studies were cotton, grain, sugar beets, tomatoes, and melons. Results have shown that substantial amounts of saline water can be used for irrigation with little yield reduction, and thus, irrigating with saline drainage is another option for drainage reduction. On-farm strategies for irrigating with saline water include:

1. Irrigating with diluted drainage water. Low-salinity water is used for crop establishment. Drainage water blended with the irrigation water is used for the remaining irrigations.
2. Irrigating with undiluted drainage water. Low-salinity water is used for crop establishment. Drainage water is used for subsequent irrigations.
3. Water table management.

The most desirable strategy may be determined by on-farm constraints. Irrigating with undiluted drainage water requires a storage facility for accumulating sufficient drainage water for irrigation, although one option would be to irrigate only those acres that could be supplied with the drainage water flow rate. (This assumes drainage flows occur during the irrigation system.) No such facility may be needed for the dilution strategy, but a distribution system may be required to continuously convey drainage water to irrigated fields. One constraint on irrigating with drainage water is the concentration of toxic materials in the water. Recent studies have shown a potential for some crops such as melons and vegetables to accumulate selenium in the plant tissues. Another constraint is the use of sprinkler-irrigation with drainage water. Research results have shown foliar absorption of salts to be a problem with some crops when high levels of salt are in the water.

The third strategy for using drainage water for crop production is water table management. Promoted in areas with low salinity, water table management involves controlling the water table depth to encourage maximum crop use of the shallow groundwater, which reduces the irrigation requirement and drainage volume.

Traditionally, where shallow saline groundwater exists, water tables are controlled to minimize upward flow into the root zone. Recent studies have shown that the shallow saline groundwater can contribute significantly to the seasonal crop evapotranspiration of selected crops, and that the contribution depends on the groundwater salinity. Figure 4.4 shows, for a groundwater with a salinity of about 10 ds/m, a maximum contribution of about 30 percent occurs for a water table depth of about 5 feet. Research results have shown no adverse impact on crop yields from utilizing the saline groundwater.

One management strategy may involve operating a subsurface drainage system and surface irrigation system as needed to maintain a favorable salt balance in the root zone, which, at the same time, will satisfy water requirements. Nonuniformly applied water is stored and redistributed by the high water table. If the entire area is considered, efficiency of surface irrigation may be comparable to what is normally achieved under sprinkle systems. Obviously, drainage and salinity control must be an integral part of the management of these surface systems.

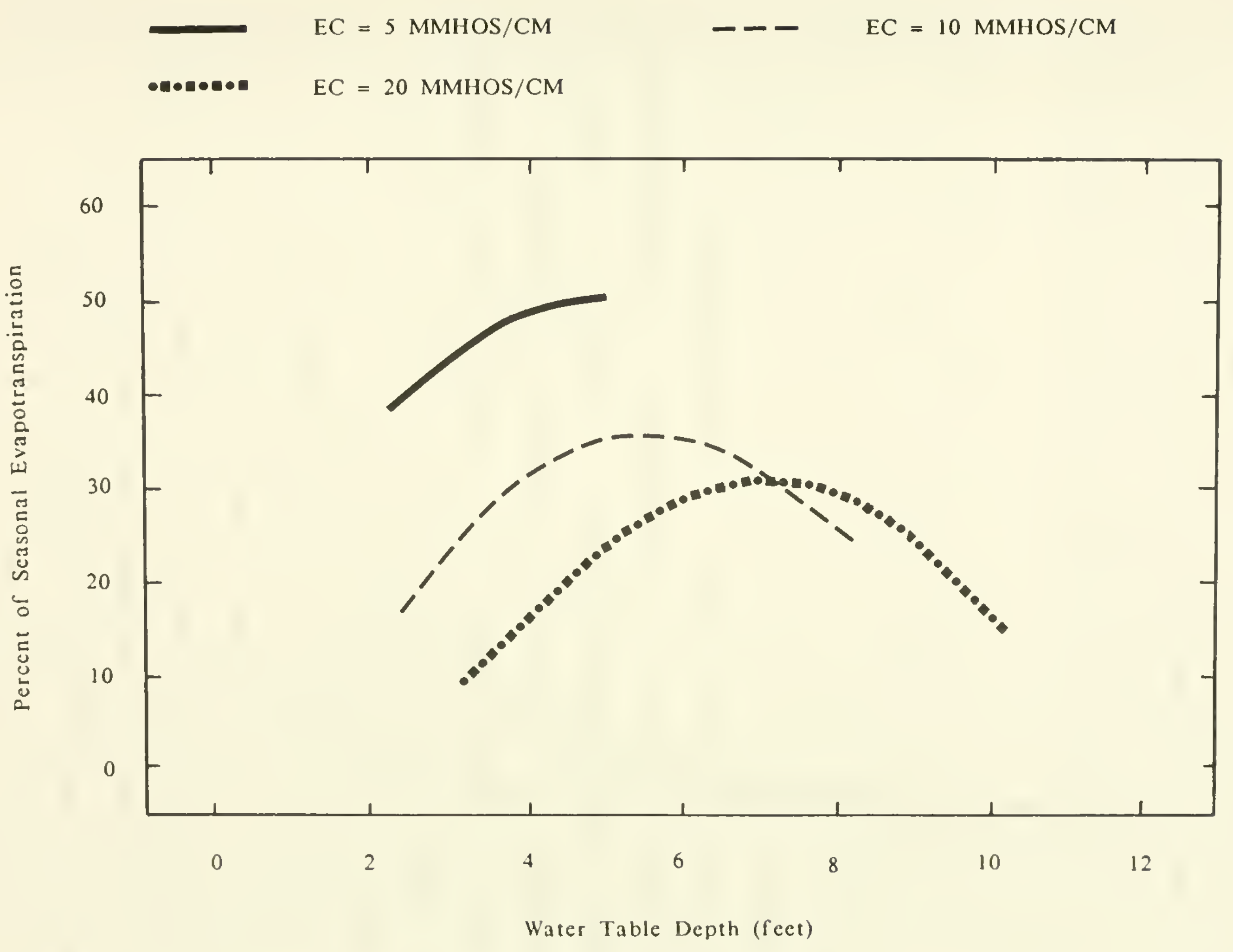

Figure 4.4 Water table contribution to seasonal evapotranspiration.

4.5.3 Leaching/Drainage

Drainage reduction, as proposed herein, would result in less irrigation water percolating through the root zone, and an increased use of saline water for crop production. This would increase the potential for excessive salt accumulation in the root zone, which would adversely impact crop yields. A salt balance favorable to profitable crop production must be maintained by periodic leaching of salts from the root zone.

A question is, however, "How much water is needed for leaching?" Numerous studies have shown the leaching requirement as a function of irrigation water salinity, drainage water salinity, and crop yield. These studies generally assume the irrigation water to be the source of salt. For the low-salinity irrigation water used along the west side of the SJV, the leaching requirement for no yield reduction would be a few percent of the applied water, and substantial decreases in the volume or subsurface drainage could occur. This would be true for areas with no water tables; however, in the high water table areas, salt accumulation in the root zone is primarily from salt transport by the upward flowing water, which can be substantial. Seasonal increases in root zone salinity of up to 30 percent of the initial salinity have been measured.

The leaching requirement for high water table areas would be higher than for areas with no drainage problems. Moreover, some areas are naturally saline and contain soluble salts from chemical weathering. Gypsum is particularly common in soils derived from marine sedimentary rocks; and, until it is depleted, it will contribute to soil salinity. Figure 4.5, which shows the depth of water per unit depth of soil needed to reduce the soil salinity by a desired percentage, might be used to estimate the amount of water needed for seasonal salinity control under saline-high water tables. For these areas, leaching may occur during the preplant

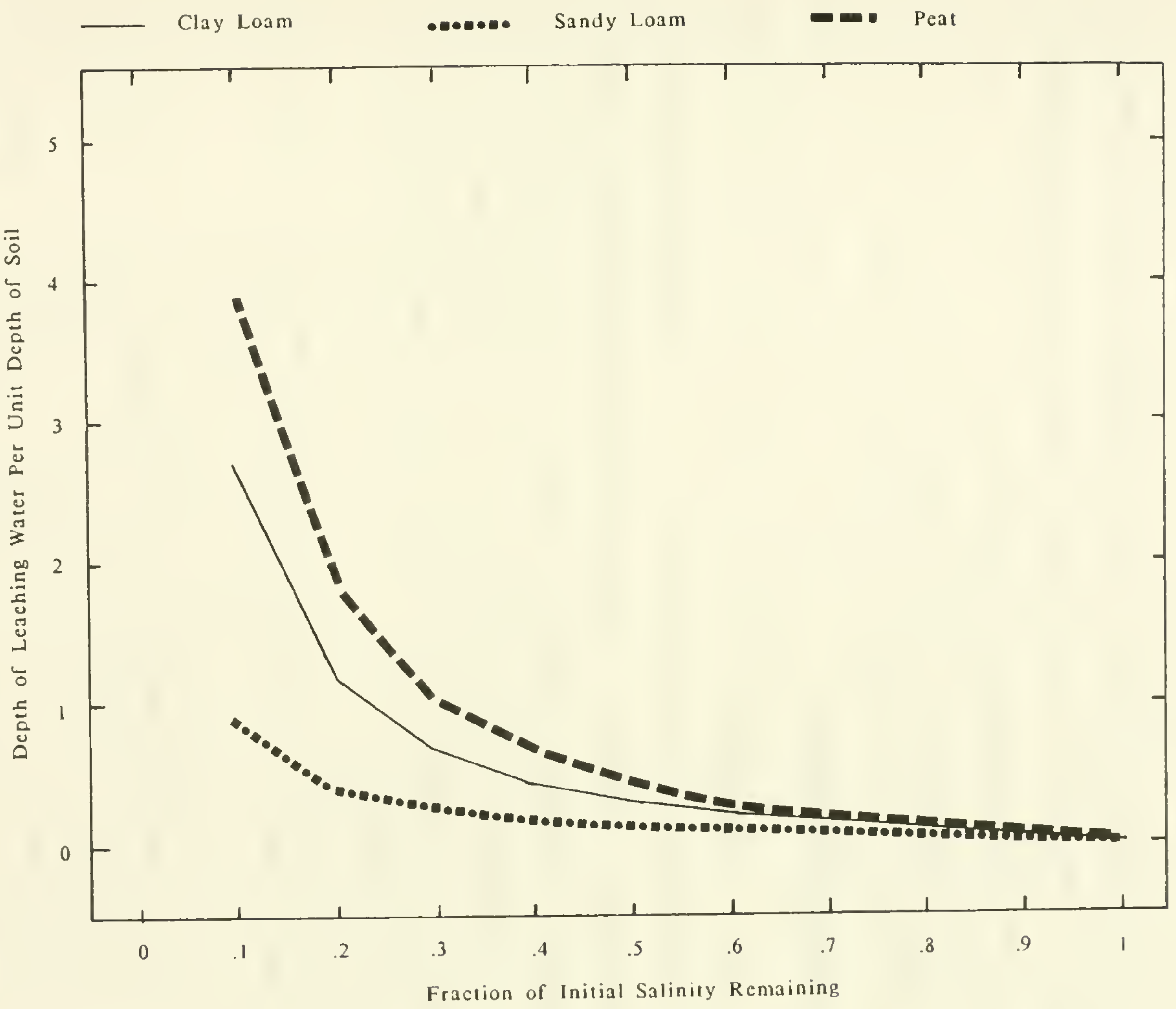

Figure 4.5 Leaching depth related to initial soil salinity.

irrigation. Researchers have shown that where preplant irrigations occurred, the spring soil salinity was the same for each year over a several year period. Where no preplant leaching occurred, salinity continued to increase over the time interval.

Some drainage disposal may be necessary. Evaporation ponds coupled with drainage water treatment may be the primary disposal method, although long-term salt accumulation in the ponds may be a problem.

4.6 AREAS OF EDUCATION AND RESEARCH

4.6.1 Demonstration Projects

Design and implementation of demonstration projects should involve grower, agency, research, and consulting personnel. Some of these projects should be more intensively studied, while others could be used as satellites to study a range of site conditions. Intensively studied sites should have a research component to test models and management strategies, which could then be used to generalize the recommendations or methods. Cost data should also be collected in conjunction with physical and biological data.

Research Topics. Three major areas of future research needs have been identified:

- Water application modeling to simulate system performance as a function of management decision. An example of a surface irrigation model use is to predict water distribution (from which performance is calculated) for shortened fields, different flow rates, different irrigation times, and from these simulations select optimum strategies.
- Saline water table management.
- Irrigation scheduling where a water table is present.

4.7 CONCLUSION AND RECOMMENDATIONS

In prioritizing high impact irrigation systems and management strategies, economic as well as environmental goals must be met. Generally, the more expensive the technology, the greater the drain water reduction potential. Ranking is done from the least capital-intensive to the most capital-intensive system. Due to the uncertainty in the relationship between irrigation technology and drain water reduction, the strategy of implementing least costly methods first, in order to assess their impact on drainage, is rational. Then, if environmental regulations are not met, more expensive technologies can be installed. However, economic incentives may be required to ensure profitability and a commitment from the banking industry to loan the necessary capital to make improvements.

Ranking Technologies.

Short-Term (0-1 year) Less Than $50/Acre

A. Improved surface irrigation to reduce deep percolation, especially in pre-irrigation and early season irrigation.

    1. Increase flow rate;
    2. Reduce length of run;
    3. Recirculate or reuse surface runoff;
    4. Cutback flow to reduce runoff;
    5. Pack soil with torpedos to reduce intake rate;
    6. Wheel pack furrows to reduce intake rate.
    7. Minimize set time difference;
    8. Maintain design inflow rate;
    9. Maintain consistency in flow between furrows.

B. In addition to correcting existing management and maintenance problems on sprinkle and trickle systems, the following improvements are recommended:

   1. Use offset lateral sets;
   2. Install flow control nozzles or renozzle;
   3. Shorten risers to reduce wind distortion;
   4. Adjust spray booms on continuous-move sprinkling systems;
   5. Convert from drop tubes to spray booms;
   6. Improve water filtration (trickle and sprinkle);
   7. Improve uniformity of pressure in system.

C. Improvements can also be made in drain water use:

   1. Manage the water table by limiting the amount of water drained early in the season. Use the water table as a means to improve uniformity and store water for later use;
   2. Irrigate with diluted drainage water. Low-salinity water for crop establishment followed by drain water blended with irrigation water for remaining irrigation.

D. Irrigation scheduling to better estimate water application.

E. Deficit irrigation.

Intermediate (1-3 years) Capital Cost Greater Than $100/Acre

A. Surge irrigate, especially for early irrigations, to avoid excess average water application.

B. Land levelling.

C. Level basin irrigate where the onflow rate is sufficient, to avoid excess water application.

D. Sprinkle irrigate for seed germination and early season irrigation to reduce excess average water application.

E. Controlled irrigation on sloping fields.

Long-Term (3-10 years) Capital Cost Greater than $300/Acre

After implementation of the short and intermediate measures, more expensive options would include:

A. Periodic-move sprinkling systems to control average water application and achieve high uniformity (under low wind conditions).

B. Modified continuous-move sprinkler systems; these are expensive but promise water control to meet strict environmental standards.

C. Trickle (tubing or surface); very expensive but, again, promises very high uniformity and application depth control with the added benefit of lesser evaporation (water use).

D. Trickle (buried tubing); the most expensive to install, but has the added advantages of no soil surface water evaporation, trafficability, and reduced soil compaction because the soil surface is dry.

Application of the suggested technologies should encourage combinations of strategies and should be flexible enough to adjust for site specific conditions which may override ordering.

SECTION 5

INSTITUTIONAL CHANGES AND ECONOMIC INCENTIVES

5.1 INTRODUCTION

It is recognized that "under existing incentives and technology, drainage load and volume exceed disposal capability." Therefore, it is desirable to seek ways to modify institutional practices and economic incentives to encourage drainage reduction where feasible. Growers can best be encouraged to adopt water conservation measures by becoming convinced that these measures will reduce drainage costs and increase profits. In plain terms, institutional changes, economic incentives, and water conservation measures need to be practical and cost effective to get grower support, and grower support is essential if those policies are to be effective.

The current level of knowledge concerning the potential impact of institutional changes on California growers is very low. Evidence suggests that given proper incentives, growers will express interest in, and comply with, water conservation programs. However, there is little conclusive evidence concerning the success rate of such programs. Determination of economic and institutional changes which are most likely to have the greatest impact on drainage flows must rely on evidence from other areas. Insights can be gained by examining grower response to programs from other states, as well as those in other parts of the world. Experiences in Welton-Mohawk, Arizona, and some in Israel and India, are examples which may have particular relevance.

In addition to water conservation programs, other types of programs such as soil conservation or integrated pest management projects could provide useful information. The goals of these programs are different from those of water conservation projects, but the incentives used to promote the goals are often the same as those which have been suggested as options to encourage drainage reduction. Identification of successes, or failures, of incentives implemented to promote related projects could lend insights to the potential effectiveness of incentives designed to encourage reduction of drainage flows.

Public and private participation in water management and conservation activities is traced below. It should be noted that the short timeline allowed for this report prevented evaluation of the relative successes of these programs, an objective which should be a top priority for future research.

5.2 EXISTING PROGRAMS

There are numerous federal, state and local programs that potentially could provide support to assist with making on-farm water management improvements. However, none of the programs has given high priority to on-farm management in drainage problem areas except for the program implemented by Westlands Water District (WWD) and the Department of Water Resources', Westside Drainage Reduction Program.

5.2.1 United States Bureau of Reclamation

The Bureau of Reclamation has several programs, policy directives, and legal authorities which mandate the development and implementation of water management and conservation plans. Section 210 of the Reclamation Reform Act (RRA) of 1982 requires districts receiving irrigation water from a Bureau project to develop irrigation water conservation plans which contain definite goals, appropriate water conservation measures, and a time schedule for meeting the conservation objectives. Since 1978, Bureau policy has required that all new irrigation water service contracts include water conservation plans, and this policy has been implemented through the inclusion of a standard water conservation clause in all new contracts. In addition, the 1978 policy requires that irrigation water conservation plans be developed before funds obtained by a water agency through the Bureau's P.L.-130 and P.L.-984 small loan programs can be released to the agency. Finally, the Bureau has developed the Water Management and Conservation Program (WMC) to promote improved water management and more efficient use of water on irrigation projects.

In 1969 the Bureau began developing a program using the principle of on-farm irrigation scheduling, which came to be known as the Irrigation Management Services (IMS) Program. The program was in effect for a number of years but was not effective and, subsequently, was not refunded. The WMC Program noted above is the result of a restructuring of the IMS Program.

5.2.2 US Department of Agriculture, Soil Conservation Service (SCS)

The SCS has three field offices in Los Banos, Hanford, and Bakersfield and an area office in Fresno. The total technical staff to handle on-farm water management is 11 persons. If the staff was given drainage reduction as a state priority, they could allocate up to 75 percent of their time for providing on-farm management technical assistance. However, this would have to occur by local Resource Conservation Districts helping to set this as a priority.

5.2.3 US Department of Agriculture, Agricultural Research Service, Water Management and Salinity Labs

The mission of the laboratory is to (1) develop advanced water management practices, methods, equipment, and systems to utilize soil, water, energy resources efficiently, and to increase agricultural productivity in irrigated agriculture; and

(2) evaluate and predict consequences of water management practices on the quantity and quality of surface goundwater.

5.2.4 California Department of Water Resources (DWR)

The DWR presently operates a Westside Drainage Reduction program with local programs being managed by Westside and Los Banos Resource Conservation Districts. The Westside Resource Conservation District program is sharing costs with cooperating farmers for irrigation management services provided by private consultants. The Los Banos program is similar to other DWR/RCD Mobile Lab programs. Another Mobile Lab available for on-farm management assistance is located in Bakersfield. These programs have been developed to help provide recommendations to improve on-farm distribution uniformity.

There are also 15 weather stations in the San Joaquin Valley in the California Irrigation Management Information System (CIMIS). Reference evapotranspiration information from CIMIS can be used to help schedule irrigations.

In addition, training courses in evaluating irrigation systems for irrigation efficiency and distribution uniformity are held twice yearly, and a demonstration and training facility for flexible water delivery is currently under construction at Cal Poly, San Luis Obispo.

5.2.5 University of California Cooperative Extension (UCCE) and Farm Advisors

The UCCE has several irrigation and drainage specialists available to provide information and education to growers. Extension specialists periodically conduct training courses and workshops. There are also farm advisors' offices in San Joaquin, Stanislaus, Merced, Madera, Fresno, Kings, Tulare, and Kern counties. All farm advisors are available for providing direct information and education to growers. However, these advisors are normally linked to certain commodities and to a wide range of agronomic practices. This limits the amount of time available for on-farm irrigation management.

5.2.6 University of California Committee of Consultants

The UC Committee of Consultants on Drainage Water Reduction has been tasked with the mission of evaluating the potential for reducing on-farm and regional drainage waters in the western San Joaquin Valley. An additional mission is to estimate the anticipated cost of drainage water reduction practices and methods and potential benefits to agriculture and other sections of society.

5.2.7 San Joaquin Valley Drainage Program (SJVDP)

This state-federal interagency program is charged with helping to solve immediate agricultural drainage-related problems on the west side of the valley and developing a comprehensive plan for long-term drainage management. Development of the plan is to be completed by October 1990. As they are completed, results of program-sponsored research and studies are available for on-farm water management improvement.

5.2.8 Westlands Water District (WWD)

WWD has had an active water conservation program in effect since the early 1970s. Information is provided to growers for irrigation scheduling using the evapotranspiration-based-water-budget method. WWD also has two staff persons assigned to provide assistance in on-farm irrigation management. Westlands initiated a program using private consultants providing services to growers on a cost-sharing basis. The program began in 1985 and is operating today.

5.2.9 Broadview Water District (BWD)

BWD implemented an information program for its growers in scheduling irrigations and evaluating irrigation systems. The program was supported in part by a small CIMIS grant from DWR that helped BWD start the program with technical support and training carried out by an irrigation consultant. The program continues to provide irrigation management information to the district's growers.

5.2.10 Berenda Mesa Water District (BMWD)

BMWD has provided information on irrigation scheduling over the past few years. Recently, with a small grant from DWR, BMWD developed a program with a consultant to provide crop evapotranspiration data.

5.2.11 Private Consultants

A number of firms in the San Joaquin Valley provide on-farm management services. The services include recommendations on irrigation scheduling and irrigation system evaluation along with recommendations on preirrigations and leaching requirements. Both Westlands Water District's program and DWR's Westside Drainage Reduction program are working with a number of these consulting firms.

5.2.12 Summary

In conclusion, programs exist to deal with on-farm water management, but funds have been limited and results have been incomplete. Institutions that can support such activities need to address this as a high priority and direct more staff and funds to increase efforts. The experience of these programs suggests that programs to provide for sharing a farmer's costs for irrigation management consultants may be the most efficient approach. However, beyond that, fundamental changes in economic incentives and institutional practices need to be made in order to fully implement effective water conservation programs.

5.3 WATER MANAGEMENT INCENTIVES

While it is not clear that one incentive program exists that is clearly superior to the rest, it is clear that a successful program must contain a large number of components. Without a variety of incentives, it is unlikely that a water conservation program could accommodate the great diversity of circumstances faced by valley growers and would not enjoy widespread participation.

The program components to be examined can be seen to fit into one or two categories. They will either involve incentives necessary to address on-farm management decisions directly, or they will be institutional changes designed to influence the environment in which the grower operates. The latter category includes, for example, district-level changes, which affect the timing and flexibility of water deliveries, as well as those changes addressing banking institutions and financing options for growers. It is also recognized that adjustment costs and implementation timelines will differ among the various incentive options. These alternatives span the spectrum of market solutions to those imposed by regulation. Solutions can be divided into those that can be implemented in the near future and those that represent long-term approaches.

With this in mind, a "shopping list" of incentives is devised. The following incentives are identified and defined without evaluation of their potential for success.

5.3.1 Water Year

Water year schedules act as constraints on the ability of growers to adapt to uncertain rainfall conditions. Changing water years, typically from January-December to March-February, allows growers to increase the efficiency of preirrigations by making use of January and February rainfall and moving preirrigation applications closer to the time of crop need. The March-February water year more closely matches the hydrologic cycle and appears to be the optimal year.

Broadview Water District utilizes the March 1 water year. A recent study indicates that growers in Broadview are responsive to rainfall conditions in scheduling preirrigations (Wichelns, et. al., 1987). All districts receiving water from the San Luis Unit of the Central Valley Project were switched to the March 1 water year for the 1986-87 season. There is little conclusive evidence on the effectiveness of that change, due primarily to the limited amount of time it has been in effect and the shortage of rainfall during the 1986-1987 pre-plant period. Changing the water year is seen to be a short-run option, as it has already been implemented for a large portion of the study area.

5.3.2 On-Demand Delivery

On-demand delivery allows the grower to order water at the time of need, rather than be constrained to a prearranged irrigation schedule. Availability of on-demand delivery enables growers to fine-tune irrigation schedules to weather and field conditions and improves irrigation efficiency. The primary constraint to on-demand deliveries is the capacity of the district delivery system. On-demand delivery is seen to be a desirable short-run option for districts with adequate capacity. For districts without adequate capacity, there is potential to improve schedule efficiency through small-scale capital improvements such as electronic gates.

A survey of current operating practices of districts in the study area indicates that in all areas, under normal conditions, water will be delivered within 24 hours of the time of request.

5.3.3 Pricing

"Pricing" includes tiered (increasing block) irrigation water and drainage charges. Prices paid by growers for their water allocations can be adjusted to include a drainage fee or can be tiered such that each successive unit of water is priced higher than the previous one. These price increases can be based on water usage or can operate as an effluent fee based on measured drain flows.

In theory growers will respond to higher prices by decreasing their water usage. The degree of success of this type of incentive depends on how responsive growers are to changes in the price of water. In addition, short- and long-run responsiveness will differ with the relative ease with which water conservation practices can be implemented. More information is necessary before accurate predictions regarding the effect of a price change can be made.

Districts generally can impose higher prices where they can be justified on the basis of increased drain water management or other costs, but cannot raise them above the actual cost to the district. The greatest impediment to pricing changes is the need of the district to cover contract costs to the water wholesaler. The concern is that as total sales decrease due to increased prices, total revenues may drop below the level that the district needs in order to meet its contractual obligations. This problem could be addressed through the use of water markets, or water credits and contract changes (discussed in Sections 5.3.4 and 5.3.5).

Other concerns include the ability of the district to gain grower approval of increased charges and the potential incentive created to increase groundwater pumping to compensate for decreased purchases of surface water. Recent events in Westlands and Broadview Water Districts indicate increasing realization by growers that they will have to accept higher drainage costs. In addition, the high pumping costs of west side groundwater are expected to preclude the latter problem from becoming serious.

5.3.4 Water Markets

Implementation of a water market would enable growers to buy or sell water so that it could move to uses of greatest value. California has enacted legislation, which expands the opportunities for water transfer and marketing, but organized water markets have not developed and relatively few interdistrict water transfers have occurred. The often multilevel agreements that must be obtained before a water transfer can be effected and the uncertainty in legal and institutional rulings on water markets makes this a long-run proposition.

The ultimate potential for water marketing to encourage on-farm water conservation is perhaps greater than for any other institutional change. However, the implementation process can be expected to be long and difficult. It is possible that federal legislation will be necessary for market formation, if federally supplied water is a candidate for transfer. Currently some support for the creation of a formalized mechanism by which federal water can be transferred exists, but many issues remain unresolved. Such issues include allowing water to be transferred for use outside of the authorized service area and allowing a grower to keep profits resulting from a water transfer. Controversy surrounding the latter issue focuses on the fact that the water cost paid by the grower was subsidized by U.S. taxpayers. It should be noted that the USBR will not take the initiative on this issue but that there is evidence that it would be open to formalizing transfer procedures. Similar problems exist for marketing state water though there are fewer impediments than with federal water. Organized promotional efforts must begin as soon as possible if this mechanism is to be realized in the near future.

5.3.5 Water Credits/Contract Changes

Many existing contracts require districts to pay for a specified annual entitlement irrespective of grower demand. Contract changes which would allow districts greater flexibility to adjust the quantity of water purchased without fear of financial repercussions are desirable. Under this system the wholesaler either keeps unused water and does not charge the district for it or gives the district credit for unused water. Water credits allow the district to postpone delivery of the water until the time at which it is needed. Though this option has great potential for immediate results, it may be a mid- to long-term option because of the complexity in balancing increased flexibility with the need to repay stated federal project costs.

5.3.6 Capital Financing Options (Basin, District, and On-Farm Levels)

Inadequate access to capital may inhibit the ability of growers to finance on-farm irrigation system improvements that require capital investment.

One option for encouraging on-farm adoption of water management technology is to implement a district purchasing program. Under this scenario the district would purchase the equipment and then rent it to the grower. To facilitate this type of cooperative buying program, it will be necessary to support district financing, perhaps through a state-supported bond issue.

Secondly, it is recognized that increased efforts to educate lenders as to the long-run value of such capital investments may increase the availability of private financing.

5.3.7 On-Farm Management Incentives

In addition to adoption of water management technology (see Capital Financing, above), better management of existing systems can reduce on-farm water use, e.g., shortening runs in furrow irrigation.

Grants or loans designed to promote such options as hiring qualified irrigation management specialists or purchasing computer software could increase irrigation and monitoring efficiency. Precedent for the former option has been set by Westlands Water District. Publicly supported, personalized service has also enjoyed success through the Mobile Lab and CIMIS programs.

Computer technology could be promoted at the individual level through software development and seminars or with a centralized system, such as that adopted in the Midwest, where farmer co-ops provide weekly computerized irrigation schedules for all members.

5.3.8 Fund Collection Options

Within the study area, some lands have drainage problems while others do not. The hydrologic relationships between upslope irrigation and downslope drainage problems are not well understood. There is general consensus that upslope irrigation contributes to downslope drainage flows, though the extent of these contributions is not yet known. Consideration must be given to whether drainage-associated costs should be borne by all irrigators or only by those growers who install drainage systems and, thus, benefit directly from the drainage projects. Westlands Water District provides an example, whereby all growers pay some drainage costs while growers benefiting directly pay a higher proportion of the charges.

5.3.9 Cost-Sharing Options

To the extent that some benefits from drainage reduction are in the public interest, the argument can be made that the general public should make financial contributions in proportion to benefits received. Benefits from drainage solutions could include improved public health, water quality, and fish and wildlife habitat.

One avenue for public support is to increase capital availability to growers, perhaps by underwriting low interest loans. This would facilitate investment in conservation technology for which bank loans may be unavailable.

5.3.10 Regulatory Pressure as an Incentive

The regulatory environment within which growers must operate is influenced by federal and state regulation and by district rules.

Regulation has already closed drains in Westlands Water District and will restrict flows through Grasslands. State and federal regulations impact on growers through district policies. For example, districts may choose to limit the amount of drainage water accepted for treatment or disposal.

One set of regulations are those established by Title 23, Subchapter 15, of the California Administrative Code, which regulates the disposal of liquid wastes. In addition, toxic elements in drain water increase the role of agencies such as the Department of Health Services and legislation, such as the Toxic Pits Act. In the near future, water quality standards for the San Joaquin River can be expected to modify grower operations.

Future regulations may be imposed, which mandate irrigation efficiency levels. This is not seen to be a desirable alternative, given the decentralized nature of the businesses involved and variability of field conditions. In addition, mandated efficiency levels are extremely expensive and complicated to implement.

5.3.11 Regional Drainage Authorities

Perhaps the best way to organize efforts toward drainage reduction is through regional drainage authorities. Formation of a drain management district would facilitate implementation of water management improvements and arrange equitable financing for such improvements.

The boundaries for districts would most likely be determined by local water districts. Options range from drainage districts formed within each existing water district to a regional district encompassing the entire study area.

In principal, the drainage district would assess a charge to all members of the district, then recycle the money in the form of incentives to growers who wish to decrease their drainage volumes. To increase interest in the district, state cost-sharing monies could be used to supplement these incentives.

Enabling legislation was passed in the early 1900s that allows for drainage district formation by a majority vote. It is recognized that there may be some problems associated with gaining the necessary voluntary grower support. District formation may require incentives to join as well as penalties for not joining. Incentives could be in the form of state financing, while penalties may be in the form of regulatory pressure from the Regional Water Quality Control Board.

5.3.12 Land Use Changes

Changing land use from historically irrigated agricultural uses may be a means of reducing the selenium content in drainage waters as well as decreasing its volume. Agroforestry and upland wildlife habitat are two examples of alternative uses for the land. Land use changes could result from voluntary farmer decisions or a government buy-out program. The latter alternative would most likely focus on lands contributing drainage with high selenium concentrations. Too little is currently known about the hydrologic relationships of drainage flows to determine the potential effectiveness of this type of program. Therefore, this should not be considered a good short-run alternative.

5.3.13 Participation in Agricultural Stabilization and Conservation Service (ASCS) Agricultural Conservation Program

The ASCS' Agricultural Conservation Program is a potential economic incentive for funding water conservation and drainage reduction equipment. Up to $70,000 can be cost-shared 50 percent with growers under long-term agreements. Current program funding levels are relatively limited and regulations are somewhat restrictive; however, the Agricultural Conservation Program is in place and operating through county ASCS offices in drainage-impacted counties.

5.4 CONCLUSIONS

- Drainage reduction through water conservation practices may well be more cost-effective than providing for drainage water treatment and disposal but will require incentives and institutional changes to be effective.
- Drainage reduction is likely to occur slowly as incentive programs and institutional changes take time to set in place and because grower acceptance is likely to occur slowly.
- While several federal, state, and local agencies have effective ongoing water conservation programs, more effort is needed to achieve further significant drainage reduction.
- A wide variety of incentives and institutional changes will likely be needed to accommodate the great diversity of circumstances faced by valley growers.
- Growers must believe that incentives, disincentives, or institutional changes would save them money or increase production if they are to reduce drainage.

- Both incentives, such as cost-sharing, or disincentives, such as block irrigation water charges, can lead to drainage water reduction by inducing growers to use less irrigation water.
- Growers are likely to resist the imposition of disincentives.
- Federal and state enabling legislation and policy changes will be necessary to allow certain incentives and institutional changes to take place.
- Certain changes, such as increasing block irrigation water charges, cannot be implemented without institutional changes.
- Regional entities will probably be needed in order to fairly allocate costs connected with drainage production and reduction.

5.5 RECOMMENDATIONS

- That the Agricultural Water Management Subcommittee continue to identify drainage water reduction incentives that are practical in terms of implementation and grower acceptance.
- That the subcommittee study and recommend legislative and policy initiatives to further the goal of drainage water reduction.
- That the subcommittee solicit proposals with the objective of furnishing institutional or policy changes or economic incentives to promote drainage reduction.
- That the subcommittee analyze and recommend ways to develop a stronger coordinated program among local, state, and federal agencies that are providing on-farm management assistance to effectively reduce drainage volumes.

SECTION 6

AN EDUCATION PROGRAM FOR DRAINAGE REDUCTION

6.1 INTRODUCTION

The key to a successful, effective water management/drainage reduction program is recognition and participation by growers in drainage regions. In reviewing the available water management programs and research, it appears that a tremendous void exists between the scientific theory and its practical, on-farm use. Bridging this gap to encourage the use of effective on-farm water management practices by all growers in drainage problem areas is, perhaps, one of the most difficult tasks ahead for persons involved with the San Joaquin Valley drainage problem.

6.1.1 Importance of Drainage Reduction

To encourage participation in a drainage reduction/water management program, a grower must be made aware of the drainage problem and the costs associated with managing it. Any potential treatment or disposal program for drainage water will be costly. A grower must be educated that the cost of a drainage treatment or disposal program can be offset by reducing the amount of drainage water requiring treatment or disposal.

6.1.2 It Is Everyone's Problem

The drainage water originating from the west side of the San Joaquin Valley is not labeled according to a particular farm or water district. The water does not carry "upslope" or "downslope" identification. It is mixed with other drainage water and, in some cases, fresh water. It is everyone's drainage water (albeit in varying amounts), and, consequently, everyone's problem.

Studies identifying the origin of the drainage water could provide valuable information and might well serve as a basis for determining cost-sharing for a drainage management program. Until such information is available (providing it is possible to develop this data), efforts should continue to focus on the regional aspect of the problem and the need for regional solutions. Each district, water user, and landowner in the drainage problem area must be made aware of the value of his direct participation in a drainage reduction program and the role such a program will play in ultimately solving the drainage problem.

6.2 WHERE TO BEGIN: DEMOGRAPHICS

Before an effective education program can be implemented, demographic information about the drainage service area must be collected. Using this information, an educational plan and a marketing strategy should be developed that identifies the motivational factors needed to encourage grower and district participation.

Demographic information for the plan could be developed in coordination with current surveys conducted by other agencies. Data gathered would include farm size, crops produced, crop yields, costs of water, acreage affected by a high saline water table, acreage with subsurface tile drainage systems, and current drainage treatment and disposal practices. Other useful information would include irrigation methods in use, how irrigation decisions are made for each crop, and irrigation system features. The survey should identify whether growers know how much water they apply during each irrigation and methods used to determine that amount. Growers should be asked what changes in irrigation systems and equipment they would make if inexpensive capital were available.

Effective communication must be a two-way street. Feedback from participants is vital for continued success of a drainage reduction program. The participants' evaluations of drainage water reduction efforts can help strengthen the weak points and offer suggestions to improve overall effectiveness.

6.3 EDUCATION PROGRAM COMPONENTS

Currently, various state, federal, and local agencies, and individual water districts offer several programs that focus on improved irrigation management. A cooperative effort by these entities is needed to focus attention and encourage participation in regional drainage reduction efforts.

Several of the existing programs support education and deserve continued funding, while additional funding is required for new programs. Existing programs include use of the DWR-sponsored mobile water conservation laboratory, on-farm demonstrations, workshops and short courses, and district and/or regional water management programs. New programs would include development of educational video tapes and organization of a "Drainage Action Team." Regional newsletters, periodic information sheets, and media contacts are other useful ways to communicate with growers and key players in drainage problem areas.

6.3.1 Expanded Use of the Mobile Lab

The mobile irrigation water management lab is an effective, well-accepted program. The mobile lab is available to growers in their local areas, usually during the peak irrigation season. The lab can evaluate all major types of irrigation systems, including furrow, border, drip, and sprinkler systems. Depending on the evaluation, recommendations can be made to growers on management or physical changes to improve irrigation uniformity and application efficiency of the system. Expanded use of the mobile lab to focus on improved irrigation management and its relationship to reducing the drainage effluent can be a very useful way to educate growers and should be encouraged.

6.3.2 On-Farm Demonstrations

On-farm demonstrations of various irrigation systems and management ideas can be useful. For growers, demonstrations (field trials) may be the only acceptable proof of the success of improved irrigation management and drainage reduction, providing it follows certain criteria. Based upon grower suggestions, it appears that on-farm demonstrations need to be conducted on a larger scale, reflecting a more typical west side farm situation. For example, the benefits derived from use of a surge or drip irrigation system in row crops may be more believable if the trial is conducted on a representative range of conditions of a large field of 150 acres or more. Increasing the size of the demonstrations, proper timing of demonstrations, and credibility of the grower participating in the field trials are key considerations for those persons conducting the demonstrations.

Demonstration meetings conducted in Spanish may facilitate better understanding of a new system by the irrigation foremen and irrigators. In planning demonstrations, cooperation from employers is essential.

Demonstrations provide opportunities for cooperation by university researchers, water district specialists, commercial irrigation vendors, and growers. Agricultural lenders should be encouraged to participate in the demonstrations to become aware of the short- and long-term benefits of funding capital investments in irrigation conservation and equipment systems.

6.3.3 Workshops/Short Courses

Properly constructed workshops and short courses regarding improved irrigation management and new systems can be helpful for educating growers. These workshops should be geared for growers, irrigation foremen, and irrigators. Attendance of agricultural lenders at these workshops should be encouraged.

The location of the workshops should be based on relatively short traveling distances for the growers. A breakfast or luncheon held in conjunction with the program is an excellent way to increase attendance.

Information presented at the workshop or short course for growers should include grower testimonials. The success of one grower's irrigation management changes can be very worthwhile to other growers, who in all likelihood, face the same or similar obstacles. Panel discussions with growers representing different areas of the drainage region are advisable.

6.3.4 On-Farm Water Conservation and Management Programs

Some districts have instituted water conservation and management programs for their water users. Westlands Water District and the Westside Resource Conservation District, for example, have developed similar voluntary, cost-sharing water management programs, which have received overwhelming interest from growers. The districts assist program participants with the cost of hiring professional irrigation management specialists to evaluate and recommend changes to their present methods of irrigation. A similar program expanded tc include growers on a regional basis may be an effective method of grower education.

Another method of educating growers of the importance of drainage reduction is the availability of water management specialists on a district basis. Because of size and funding limitations, many districts in the drainage problem area do not have full-time staff available to work on improving water management techniques with their water users. To assist these districts, a professional water management specialist could be assigned to work with the individual districts on a temporary, rotating basis. This specialist could work with each district's water users for a specified amount of time. The details of funding such a program would have to be reviewed. Perhaps, cost-sharing among the various districts participating in this program and the state or federal governments might be considered.

6.3.5 Education Video Tapes

Video-taped programs are useful educational and informational tools. A video tape explaining the geological development of the San Joaquin Valley as it relates to irrigation and drainage would be useful to educate growers, decision makers, and the general public. A second video tape would focus on farm water management options for drainage reduction. This video could be available for growers to borrow for their individual viewing or to share with employees. The video also might be available for viewing at water district board meetings, grower organization meetings, or workshops. Additional video tapes could address other appropriate topics relative to the drainage issue.

Since these video tapes will be useful in implementing the recommendations made by this subcommittee, funding for their production should be a high priority.

6.3.6 Drainage Action Team

A unique plan for bringing information personally and emphatically to growers in the drainage problem area involves forming an "ACTION" team of drainage area representatives to convey the need for a regional approach to the drainage problem. The team members, three or four persons having the latest information and briefed on specific conditions for the target areas, would meet with water district policy makers, small local groups of growers, and other opinion leaders to informally discuss the impact of drainage problems and encourage meaningful drainage reduction measures.

Team members might be growers, University of California farm advisors and specialists, district personnel, consultants, and state and federal drainage experts. Because of the size of the drainage problem areas, several teams may be necessary to fill the need. Effectiveness of the team would hinge on the team members' credibility, communication skills, and enthusiasm. Cooperation and approval of the program from the local water districts is essential to its success.

A central coordinator of the information and educational efforts of the team is needed. This person(s) would handle logistics of the program such as preparation of schedules, agendas, and handling of communications. The questions of funding, staffing, and who would provide direction for the team and target area need to be addressed before such a program is initiated.

6.3.7 Regional Newsletter/Periodic Information Sheets

A regional, monthly newsletter for growers in the drainage area could communicate the message of drainage reduction. A newsletter, with the regional appeal of the "Land Preservation Association (LPA) News," can be developed specifically for growers in the target area. This might be accomplished by expanding the distribution of the "LPA News" to include west side growers.

One-page, single-theme fact sheets can provide useful information to growers. The fact sheet should use the grower-testimonial approach whenever possible. "Profitable Practices," a single-page water management information sheet produced by Westlands Water District, serves as a current example.

The information sheet should be straightforward, clearly written, jargon-free, and presented in an attractive, attention-getting manner. Photos should be used when possible and the sheets hole-punched for use in loose-leaf notebooks to encourage growers to store the reports for future reference.

6.3.8 Media Communications

A communications program should involve local and regional print and electronic media. News releases, followed by direct communication with trade-press and general assignment reporters, are helpful in disseminating information. Emphasis should be placed on getting news coverage in daily and weekly newspapers within the region. Other examples of media use include letters to the editors of local and regional newspapers and magazines, radio talk shows, and cooperative advertising in print and broadcast media.

6.4 CONCLUSION

There have been many efforts aimed at educating growers about methods of improving irrigation systems and management. Some are more readily accepted than others. However, when the focus of water management is centered on the benefits of drainage reduction and its potential for reducing the costs associated with treating or disposing of drainage water, its importance is seen in a new light. Once this point is realized, it may provide enough incentive to encourage efficient use of irrigation water and effective control of drain water. However, growers will not risk a reduction in crop yields only for the conservation of irrigation water.

The bottom line is money--the costs of reducing drainage effluent vs. the cost of disposal of drainage effluent vs. the cost impact on crop yields. A successful communication and education effort should keep this point clearly in focus when plans are formulated.

SECTION 7

CONCLUSIONS

7.1 GENERAL

Agricultural drainage water reduction using aggressive, innovative methods provides the greatest short- and intermediate-term vehicle for reducing drainage volumes in a cost-effective manner. Drainage volumes must be significantly reduced to respond appropriately to regulatory pressure and minimize the capital requirements for facilities, treatment, or disposal of drainage effluents.

A regional approach must be taken when implementing an aggressive drainage reduction program. The geographic area impacted is large and varied. Individual growers, water districts, agencies, and political subdivisions are not presently structured to deal with a problem of the complexity and magnitude as that of agricultural drainage. Significant progress in drainage reduction will be hastened by formation of regional drainage entities and a regional perspective by involved persons and agencies.

Because of intense regulatory pressure and severe public scrutiny, management decisions and institutional changes will need to occur before all needed research is completed, reports are written, and master plans are developed. An assertive leadership role must be assumed by those individuals, agencies, bureaus, and legislators in positions to influence the direction of resolving the drainage problem.

7.1.1 Drainage Relationships

- Drainage in west side soils is severely impacted by impermeable clay layers at various depths.
- The importation of irrigation water has caused significant increases in the volume of subsurface drainage water.
- Naturally occurring toxic elements and salts in the soils move with groundwater toward the valley trough; i.e., the San Joaquin River.
- The greatest sources of excess drainage are (not necessarily in order of volume) excessive preirrigation, seepage from unlined conveyance and collector systems (and some lined but cracked structures), seepage from major reservoirs and holding basins, and nonuniformity of irrigation applications.
- Drainage volumes and quality from specific geographic areas are not yet clearly understood.
- Drainage water, in some instances may be used as a crop production resource.

7.1.2 Irrigation Practices and Emerging Technologies

- Application Efficiency (AE) is an accepted measure of irrigation performance.
- Distribution Uniformity (DU) is a much better measure of irrigation performance.
- When measuring irrigation system performance and management strategies to maximize profits, technologies should be selected that reduce drainage, achieve a desired environmental quality, and, at the same time, realize acceptable profits.

- Short-term technologies that can be accomplished with little research:
    a. improve distribution uniformity of furrow irrigation by increasing inflow rates in combination with a tailwater return system or cutback flow system and reducing run lengths;
    b. relevel fields to establish a uniform grade;
    c. manage the water table by limiting the amount of water drained early in the season;
    d. irrigate with diluted drainage water;
    e. evaluate existing systems and schedule irrigations to better estimate water application and deep percolation;
    f. use deficit irrigation.
- Intermediate-term technologies and strategies that require some research and education:
    a. surge irrigate, especially for early irrigation, to avoid excess average water application;
    b. cablegate on sites where appropriate;
    c. level basin irrigate where adequate volumes are available and sites are appropriate;
    d. sprinkle irrigate for early season and seed germination irrigations.
- Long-term technologies and strategies that will require substantial research:
    a. periodic-move sprinkling systems to control average water application and achieve high distribution uniformity (under low wind conditions);
    b. modified continuous-move sprinkler systems;

  c. trickle (subsurface or surface); is expensive but high uniformity and application depth control;
  d. trickle (buried tubing).

- Application of all technologies should encourage combinations of strategies and should be site specific.

7.1.3 Institutional Changes and Economic Incentives

- Drainage reduction through water conservation practices may well be more cost-effective than providing for drainage water treatment and disposal but will require incentives and institutional changes to be effective.
- Drainage reduction is likely to occur slowly as incentive programs and institutional changes take time to set in place and because grower acceptance is likely to occur slowly.
- While several federal, state, and local agencies have effective ongoing water conservation programs, more effort is needed to achieve further significant drainage reduction.
- Additional water conservation incentive or disincentive and institutional changes are needed to bring about significant additional drainage reduction.
- A wide variety of incentives and institutional changes will likely be needed to accommodate the great diversity of circumstances faced by valley growers.
- Incentives and/or institutional changes need to be perceived by an individual grower as saving money and/or increasing production if they are to be effective in drainage reduction.
- Incentives can be positive (as in cost-sharing) or negative (as in increasing block irrigation water charges). Both can lead to drainage water reduc-

tion by inducing growers to use less irrigation water.

- Growers are more likely to resist negative incentives rather than positive ones.
- Federal and state enabling legislation and policy changes will be necessary to allow certain incentives and institutional changes to take place.
- Certain incentives (such as increasing block irrigation water charges) cannot be implemented without institutional changes.
- Some regional institutions will probably be needed in order to fairly allocate costs connected with drainage production and reduction.
- The most effective institutional change to reduce excess drainage in the short-term is to encourage water wholesalers (state and federal water agencies) to permit water districts the flexibility to adjust the quantity of water purchased without financial penalties.
- Institutional and economic changes and incentives needed for the intermediate term are:
    a. institute regional drainage entities to facilitate implementation of water management improvements.
    b. tiered or block water pricing, where possible and consistent with California water law, to encourage water conservation and drainage reduction.
    c. capital financing by public or private sources to fund district and grower water management improvements.
    d. on-farm water management incentives to encourage water conserving technologies and improve management of existing systems. Cost-sharing designed to encourage hiring of qualified specialists would facilitate this process.

- Changes and incentives for the long-term:
    a. Water marketing would enable growers and districts to sell or buy water allocations permitting water to move to the users of highest value.
    b. Land use changes in areas of high trace element concentrations may decrease drainage volumes and reduce the selenium content of drainage water.
    c. Fund collection options would allocate costs either on the basis of upslope-downslope contribution or adding all drainage-related costs to base water charges.
    d. Cost-sharing options recognize that some benefits from drainage reduction are in the public interest and the general public should make financial contributions in proportion to the benefits received.

7.1.4 Information and Education Requirements

- The key to effective water management/drainage reduction is participation by growers and water districts. This can only be achieved by developing a regional focus.
- The gap between existing, available technical information and practical on-farm use is wide. This gap must be closed quickly.
- The most effective education and information efforts needed to reduce excess drainage volume in the short-term follow:
    a. research on management systems of growers and districts in drainage-impacted areas,
    b. develop a marketing plan prior to initiation of an informational educational program.

c. A drainage action team would bring information personally to growers in drainage impacted areas.

d. initiate workshops and short courses on the use of improved irrigation management.

e. initiate a regional newsletter such as the "Land Preservation Association (LPA) News" to be developed specifically for growers.

f. initiate positive media communications efforts with local media.

- Intermediate-term action that can be taken to meet education and information efforts:

  a. On-farm demonstrations on the use of various techniques and systems to reduce drainage volumes.

  b. On-farm water conservation and management programs to cost-share the hiring of professional irrigation management specialists will improve the skill levels of irrigators.

  c. expand the use of DWR's mobile labs in impacted areas,

  d. Development of "drainage awareness" and water management videos may prove useful in educating and informing growers.

  e. Feedback from growers and districts is essential if continuous review and improvement of their efforts are desired.

- Long-term actions would consist of all of the above efforts regarding information and education.

7.2 SUMMARY

Drainage reduction is an exceedingly complex goal to achieve and will not be attained without much discussion, controversy, and hard work. It does, however, in a larger view, have the potential for being a major element of the ultimate solution of the drainage problem at the least capital cost. It is a worthwhile objective.

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